APPENDIX C: TECHNICAL APPENDICES

TECHNICAL APPENDIX C-1: USE OF THE VSP CONCEPT IN WRIA 8 SALMONID CONSERVATION PLANNING

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Introduction

This Technical Appendix describes the role of the Viable Salmonid Population (VSP) concept in Pacific salmon conservation planning in WRIA 8. Following a brief introduction to the Endangered Species Act (ESA) and listing units, this appendix includes the following sections:

- Review of the VSP parameters,
- Description of the application of the VSP guidelines in WRIA 8,
- Summary of the status of the WRIA 8 Chinook populations relative to VSP,
- Description of the identified risks to VSP, and
- Summary of the putative relationships among WRIA 8 conservation hypotheses, VSP risks, and anticipated changes in the VSP parameters.

1.1 ESA listed species

The ESA listings of 27 Evolutionarily Significant Units of west coast salmonids have catalyzed wide ranging efforts to restore degraded habitats, reform hatchery practices, and to more cautiously manage both commercial and recreational harvest. In the Puget Sound basin, listed salmonid species include Chinook salmon and bull trout throughout the watershed, and Hood Canal chum salmon. Given the largely urban character of Puget Sound, it was recognized early on that loss of habitat was a prominent cause of the decline of these salmonid species, and that habitat preservation and restoration would necessarily play a prominent role in conservation plans. It was also recognized that effecting changes in salmonid habitat in urban areas was best accomplished at the local level.

The development of conservation plans in Washington State has been organized around Water Resources Inventory Areas (WRIAs). The WRIA structure involves the division of the state into 62 areas for water and aquatic resource management, of which 23 are within the Puget Sound basin. Of these 23, the WRIA 8 planning area, which includes Lake Washington, the Sammamish River, and Cedar River watersheds, is arguably one of the most urbanized of WRIAs, a distinction that makes conservation planning particularly challenging. Adding to the challenge in WRIA 8 is the geographic and political reality that the watershed touches some 33 local governments, all of whom have been welcomed to participate in planning activities, and will be asked to take leadership in the implementation of conservation actions. Attenuating these challenges is the fortuitous fact that most of the urban development WRIA 8 is concentrated in the lower areas of the watershed and the three main salmon-producing streams (Cedar River and Bear and Issaquah creeks) have headwaters that are either protected through public ownership (Cedar River and Issaquah Creek) or, in the case of Bear Creek, in a combination of public ownership and relatively low density development. Additionally, the majority of the Chinook salmon spawning occurs in rural rather than urban reaches.

1.2 Evolutionary Significant Units

The ESA is the regulatory framework for listing, protecting, and delisting threatened or endangered species. For the purposes of the ESA, the listing unit can be either a biologically recognized species or subspecies, or a distinct population segment (DPS). The latter category was created by Congress in 1978 to protect unique genetic resources that would otherwise be lost if a particular population, groups of populations or segment of a population with a biological species were lost. Since Congress was largely silent on what constitutes a distinct population segment, the National Marine Fisheries Service (NMFS) faced a dilemma in the early 1990s when it began receiving partitions to list geographically-defined populations or groups of populations of Pacific salmon. NMFS responded by developing a science-based policy equating a DPS to an "Evolutionarily Significant Unit (NMFS 1991). Based largely on the work of Robin Waples (1991), the NMFS policy stipulated that a salmon population would be considered "distinct" for purposes of the Act if it represents an evolutionarily significant unit (ESU) of the biological species. To qualify as an ESU, a population (or group of populations) must be a) reproductively isolated from conspecific populations and b) represent an important component in the evolutionary legacy of the species. Types of information that can be useful in determining the degree of reproductive isolation include incidence of straying, rates of recolonization, degree of genetic differentiation, and the existence of barriers to migration. Insight into evolutionary significance can be provided by data on phenotype, protein, or DNA characters; life history characteristics; habitat differences; and the effects of stock transfers or supplementation efforts.

1.3 Viable salmonid populations and recovery planning

The Viable Salmonid Population concept was introduced by the National Marine Fisheries Service (McElhany et al. 2000) as guidance for determining the conservation status of populations and larger-scale groupings of Pacific salmon. While the concepts were described as a general framework for performing salmonid conservation assessments, they were also put forth as important considerations in the establishment of Endangered Species Act delisting goals.

As defined by McElhany et al., a viable salmonid population is an "independent population of any Pacific salmonid (genus *Oncorhynchus*) that has a negligible risk of extinction due to threats from demographic variation, local environmental variation, and genetic diversity changes over a 100-year time frame." They further defined an independent population as "any collection of one or more local breeding units whose population dynamics or extinction risk over a 100-year time period are not substantially altered by exchanges." A more complete description of the properties of a population that are contemplated in the VSP concept is described in detail in the following section.

2 VIABLE SALMON POPULATION PARAMETERS

Conserving and rebuilding sustainable salmonid populations is more complicated than simply meeting an arbitrary abundance goal over an equally arbitrary time period. Acknowledging this fact early in the recovery planning process, NMFS developed what they refer to as a Viable Salmonid Population, or VSP. By definition, a VSP has a negligible risk (over a time scale of 100 years) of going extinct as result of genetic change, demographic stochasticity, or normal levels of environmental variability. In developing the VSP construct and guidelines, NMFS used Ricker's (1972) definition of a stock as the basis for defining an independent population. According to Ricker, "an independent population is a group of fish of the same species that spawns in a particular lake or stream (or portion thereof) at a particular season and which, to a substantial degree, does not interbreed with fish from any other group spawning in a different place or in the same place at a different season.." Based on the current understanding of population attributes that lead to sustainability, the VSP construct is the guidance for, and goal of, ESA recovery.

McElhany et al. (2000) identify four key population characteristics or parameters for evaluating population viability status: abundance, population growth rate or entire life cycle productivity, population spatial structure, and diversity. Although NOAA Fisheries has chosen not to provide quantitative criteria for each of the parameters at this time, these parameters are measurable and ultimately will have to be defined for WRIA 8. Moreover, they should not be thought of as boxes to be checked on a data sheet with easily defined pass/fail criteria. They are, in fact, critical factors influencing extinction risk. The reason that certain other parameters, such as habitat characteristics and ecological interactions, were not included among the key parameters is that their effects on populations are implicitly expressed in the four key parameters.

2.1 Abundance

Population size is perhaps the most straightforward of the VSP parameters, and is an important consideration in estimating extinction risk: all other factors being equal, a population at low abundance is intrinsically at greater risk of extinction than is a larger one. The primary drivers of this increased risk are the many processes that regulate population dynamics—particularly those that operate differently on small populations. Examples include environmental variation and catastrophes, demographic stochasticity, selected genetic processes (e.g., inbreeding depression), and deterministic density effects. Although the negative interaction between abundance and productivity may protect some small populations, there is obviously a point below which a population is unlikely to persist.

Based on a comprehensive review of the scientific literature, McElhany et al. (2000) provided the following guidelines for assessing the adequacy of an independent populations' abundance. The first set of guidelines describes characteristics of a viable population, while the second set identifies characteristics of populations that are considered critically low in abundance. In both cases, the authors' emphasize that "population status evaluations should take uncertainty regarding abundance into account" (i.e., abundance estimates often overestimate the numbers of fish in a population and hence a risk-averse approach should be the default in conservation planning).

A viable population…

1) *… should be large enough to have a high probability of surviving environmental variation of the patterns and magnitudes observed in the past and expected future.*

2) *… should have sufficient abundance for compensatory processes[1] to provide resilience to environmental and anthropogenic perturbation.*

[1] Compensatory processes are those in which an increase in productivity occurs with decreasing density.

3) … should be sufficiently large to maintain its genetic diversity over the long term.

4) … should be sufficiently abundant to provide important ecological functions throughout its life cycle.

A critically low population is

1)…a population that depensatory[2] processes are likely to reduce below replacement.

2)…a population that is at risk from inbreeding depression or fixation of deleterious mutations.

3)…a population in which productivity variation due to demographic stochasticity becomes a substantial source of risk.

2.2 Population growth rate

Population growth rate (λ) or productivity over the entire life cycle is a key measure of population performance in a species' ecological setting. In simple terms, it describes the degree to which a population is replacing itself. A λ = 1.0 means that a population is exactly replacing itself (one spawner produces one spawner in the next generation); whereas a λ = 0.9 means that the population is declining at a rate of 10 percent annually—a trend that is not sustainable in the long term. Conversely, a λ = 1.1 indicates a population is increasing 10 percent, a circumstance that likewise cannot continue *ad infinitum* since all habitats have an upper limit or carrying capacity. Since life cycle productivity naturally varies over broad periods of time, λ values estimated using data from long time series are highly desirable (i.e., 20+ year or more).

McElhany et al. (2000) provided the following guidelines for assessing the adequacy of a population's productivity. As was the case with abundance, the authors emphasize that, *"Population status evaluations should take into account uncertainty in estimates of population growth rate and productivity-related parameters."*

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[2] Depensatory processes are those in which a decrease in productivity occurs with decreasing density.

A viable salmonid population…

> *1) … should exhibit natural productivity that is sufficient to maintain its abundance above the viable level.*
>
> *2) … that includes naturally spawning hatchery fish should exhibit sufficient productivity from naturally-produced spawners to maintain population abundance at or above viability thresholds in the absence of hatchery subsidy.*
>
> *3) … should exhibit sufficient productivity during freshwater life history stages to maintain its abundance at or above viable thresholds – even during poor ocean conditions.*
>
> *4) … should not exhibit sustained declines in abundance that span multiple generations and affect multiple broodyear-cycles.*
>
> *5) … should not exhibit trends or shifts that portend declines in population growth rates.*

2.3 Genetic and life history diversity

Biological diversity within and among populations of salmon is generally considered important for three reasons. First, diversity of life histories patterns is associated with a use of a wider array of habitats. Second, diversity protects a species against short-term spatial and temporal changes in the environment. And third, genetic diversity is the so-called raw material for adapting to long-term environmental change. The latter two are often described as nature's way of hedging its bets—a mechanism for dealing with the inevitable fluctuations in environmental conditions – long- and short-term. With respect to diversity, more is better from an extinction-risk perspective.

McElhany et al. proposed the following diversity guidelines.

> *1) Human-caused factors such as habitat changes, harvest pressures, artificial propagation, and exotic species introduction should not substantially alter variation in traits such as run timing, age structure, size, fecundity, morphology, behavior, and molecular genetic characteristics.*

2) Natural processes of dispersal should be maintained. Human-caused factors should not substantially alter the rate of gene flow among populations.

3) Natural processes that cause ecological variation should be maintained.

4) Population status evaluations should take uncertainty about requisite levels of diversity into account.

2.4 Geographic distribution

Spatial structure, as the term suggests, refers to the geographic distribution of individuals in a population unit and the processes that generate that distribution. Distributed populations that interact genetically are often referred to as metapopulations. Although the spatial distribution of a population, and thus its metapopulation structure, is influenced by many factors, none are perhaps as important as the quantity, quality, and accessibility of habitat. One way to think about the importance or value of a broad geospatial distribution is that a population is less likely to go extinct from a localized catastrophic event or localized environmental perturbations.

McElhany et al. proposed the following guidelines for spatial structure.

1) Habitat patches should not be destroyed faster than they are naturally created.

2) Natural rates of straying among sub populations should not be substantially increased or decreased by human actions.

3) Some habitat patches should be maintained that appear to be suitable or marginally suitable, but currently contain no fish.

4) Source sub populations should be maintained.

5) Analyses of population spatial processes should take uncertainty into account.

2.5 Interdependence of VSP Parameters

Although it is instructive to dissect the VSP concept into its component parts, it is equally important to recognize that the parts are not completely independent. Taken together, life history diversity, genetic diversity, and metapopulations organization are ways that salmonids adapt to their complex and connected habitats, and are the basis of salmonid productivity and adaptability and ultimately, sustainability. Moreover, the range of "acceptable" values for life cycle productivity, diversity, and spatial distribution depend on the size of the population. Alternatively, productivity, diversity, and spatial distribution interact to determine abundance. Acknowledging the interdependence of the VSP parameters is an important consideration developing conservation actions. Actions should not and cannot be viewed in the narrow context of "fixing" or changing a single VSP parameter. Rather, the estimated benefit of a single habitat action (e.g., restoration of the connectivity of the mainstem to side-channel habitat) would likely affect all four parameters. Obviously, placing the highest priority on actions that influence multiple VSP parameters makes the most sense from both a biological and economic perspective.

3 PUTATIVE RELATIONSHIPS AMONG HABITAT CONDITIONS AND VSP

Sustained salmonid productivity requires a network of complex, diverse, and interconnected habitats that are created, altered, and maintained by natural physical , chemical, and biological processes in freshwater, estuarine and ocean environments. In freshwater, a mosaic of heterogeneous habitats supports species diversity and spatial distribution, while a variety of channel and floodplain structures creates a mosaic of habitats for the myriad plants and animals that make up the riverine food web that drives productivity and abundance. A major consequence of land management practices and development in the riparian zone, floodplain and land margins has been the disruption of habitat-forming processes, and simplification and fragmentation of salmon habitat (Reeves and Sedell 1992). Simplification is a reduction in the number and kinds of habitat types, a decrease in structural materials that make up salmon habitat (such as large wood), and alterations of physical parameters (such as temperature). Habitat simplification reduces the number of habitat types, and fragmentation disrupts connectivity and species' ability to migrate at the appropriate time between links in the habitat chain (Lichatowich 1995). Similarly, urban development has reduced native species diversity and increased inputs of toxic chemicals (e.g., PCBs, pesticides) while altering the natural balance of other important chemical and physical qualities of water (i.e., dissolved oxygen, proportion of fine sediments, and nutrients).

Stepping down from this generalized description of the habitat requirements of salmon and the impacts of past land management practices to the pragmatic connection of specific habitat attributes and actions and expected improvement to VSP is an imperfect science. Nonetheless, it is a useful step in making a more direct connection among the VSP parameters, salmon life stage, and habitat. An example of a matrix making these kinds of specific connections is shown in Table 1. While not directly used in the WRIA 8 process to identify conservations actions, these linkages provide considerable insight into the interplay between specific habitat features and environmental attributes and species response. It is anticipated that as the understanding of these linkages will increases with feedback from monitoring and evaluation.

4 APPLICATION OF VSP TO WRIA 8

4.1 WRIA 8 Chinook salmon population structure

The first application of the VSP concept to the WRIA 8 planning area was the identification of two demographically independent populations of Chinook salmon by the Puget Sound Technical Recovery Team (TRT 2001). These populations included the Cedar River and the Sammamish River…with the latter including the Sammamish River, North Lake Washington tributaries (Swamp, North, Bear, and Little Bear creeks) and Issaquah Creek. The TRT based their determination on multiple factors that they viewed as proxies for reproductive isolation. These included information on geography, migration rates, genetic attributes, life history patterns and phenotypic characteristics, population dynamics, and environmental and habitat characteristics. While it was concluded that Chinook spawning in the North Lake Washington tributaries (including Issaquah Creek and Sammamish River drainages) and the Cedar River are separate populations, it was considered uncertain whether the North Lake Washington tributaries historically supported an independent population. These tributaries are considered small relative to other Chinook-bearing streams, and their use today may be the result of a decline in body size that enables them to access and reproduce in smaller tributaries. Unquestionably, the wholesale alterations that occurred in the drainage patterns of the WRIA 8, 9, and 10 planning areas have greatly confounded any sort of straight forward analyses of population structure. These alterations include the construction of the Lake Washington Ship Canal and Locks, the rerouting of the Cedar River into Lake Washington, the rerouting of the White River into the Puyallup River, and the widespread use of Green River fall Chinook in Puget Sound hatcheries (both in and outside the Green River).

The WRIA 8 Technical Committee accepted the TRT conclusion that the Cedar River and Sammamish River were independent populations, but for conservation planning purposes took an addition step and added the naturally spawning Chinook in Issaquah Creek as a separate population to consider in developing conservation hypotheses. Among the other population structures considered was one to combine the naturally-spawning Chinook in Issaquah Creek with the North Lake Washington Tributaries and define a two population structure (Cedar River and North Lake Washington Tributaries); and another was combining all populations (Cedar River, North Lake Washington Tributaries, and Issaquah Creek) into a single "Lake Washington" population. The decision was made with full recognition that the naturally spawning fish in the Issaquah Creek were predominantly returning hatchery fish that were excess to brood stock requirements at the hatchery that were released back to the river to spawn. The WRIA 8 decision was based on a precautionary approach and the importance of this population to the local community. It is noteworthy, however, that as information becomes available on the high proportion of hatchery fish that stray into the North Lake Washington tributaries and the Cedar River, and the WRIA 8 Technical Committee may reconsider this choice. With hatchery strays (many suspected to be of Issaquah Creek origin) making up in some cases over 50% of the spawners in the Cedar River and North Lake Washington tributaries, the WRIA 8 Technical Committee is considering whether the current use of Green River-origin Chinook by the Issaquah Creek Hatchery program is perhaps more appropriately viewed as a major threat to the structure and diversity of the independent Chinook populations. Moreover, if genetic analyses indicates that the Issaquah Creek population is the same as the Green River Chinook population from which it was founded almost 6 decades ago, then the rationale for protecting this stock in this location (at least under the ESA) is of dubious value.

In considering population structure of WRIA 8, it is important to recognize the extraordinary changes that occurred in the drainage pattern of Puget Sound watersheds in the early 20th century. As noted above, historically the White, Green, and Black Rivers came together and joined the Duwamish River for discharge into Elliott Bay. The Cedar River discharged into the Black River. In 1916, the U.S. Army Corps of Engineers diverted the course of the Cedar River into Lake Washington from its original discharge into the Duwamish River, and created a new outlet to the lake when it constructed Ballard Locks and the Lake Washington Ship Canal.

The effects of these major drainage changes no doubt had equally major effects on population structure of Puget Sound Chinook salmon. With a low level of "nearest neighbor" straying and genetic exchange a common feature of salmon population biology, historic relationships among these populations were forever changed. For example, whereas historically a White River spring Chinook might easily have found its way into the Green or Cedar River, the likelihood of this would be far less today. Likewise Chinook salmon returning to the Cedar River was historically more likely to stray and spawn in the Green or White rivers than the North Lake Washington tributaries such as Bear Creek. At the same time if the North Lake Washington tributary population was present historically, it already adapted to the lake environment and was minimally affected by the drainage change. The effects of these changes are impossible to predict. Acknowledging this, the Puget Sound TRT did not consider reconstruction or complete recovery of historical population structure as a realistic goal, and accepted the WRIA 8 Technical Committee assumption that WRIA 8 independent populations were recoverable (and hence potentially viable) without reconnecting Lake Washington to the Green River.

At the same time that drainage changes were altering nearest-neighbor relationships among Puget Sound Chinook salmon populations, humans were superimposing the additional complexity of industrial-scale hatchery production in the Green River and later in Issaquah Creek -- using the same Green River brood stock for both programs. While the consequences of these transfers and nearest-neighbor shifts have been the subject of considerable speculation, there is no way to know with any certainty what the long-term consequences were or will be in future. Adding to the uncertainty have been changes in average age and size at return that have been attributed to selective harvest.

4.2 VSP and conservation planning

The WRIA 8 Technical Committee utilized three analytical tools to identify conservation strategies for Chinook salmon habitat protection and restoration. These tools included the VSP guidelines, a Watershed Rating and Screening Matrix, and the habitat-based Ecosystem Diagnosis and Treatment model. The VSP concept and parameters were used in several ways: First as a framework for organizing and summarizing population data; and second as a perspective from which to identify threats or risks. That is, what are the factors or risks that represent the greatest obstacles to achieving VSP status? Subsequent sections of this technical appendix summarize the status of the WRIA 8 populations relative to VSP, identify threats to VSP, and draw some preliminary conclusions about the types of actions are most likely to improve the status of the three Lake Washington populations in WRIA 8.

5 THE STATUS OF WRIA 8 CHINOOK SALMON POPULATIONS RELATIVE TO VSP

The current abundance, productivity, diversity, and spatial distribution of the three WRIA 8 populations are summarized in Tables 2, 3, and 4. Although comparisons to historic status are not particularly meaningful due to the drainage changes in the watershed, there are several observations that can be made. All of the populations are dangerously small, they are not replacing themselves, they are spatially restricted, and they exhibit limited life history diversity.

5.1 Cedar River

In the Cedar River Watershed, Chinook salmon utilize the mainstem Cedar as well as several tributaries, including Taylor, Peterson, lower Rock, Madsen, and Molasses creeks, and Walsh Lake Diversion Ditch.

5.1.1 Abundance

Based on the return years 1997 – 2001, the NMFS Biological Review Team (NMFS BRT 2003) reported a 5-year geometric mean abundance of natural spawning Chinook salmon in the Cedar River of 244. A recent calculation based on the return years 1998 – 2002 yields a geometric mean abundance of 327. While this suggests a modest increase in abundance in recent years, even the larger number is low enough to represent a significant risk to the population. Moreover, compared to returns in the 1970s which ranged from 3,000 to 14,000 naturally spawning fish, these recent estimates suggest a population that is in steep decline.

5.1.2 Productivity

The NMFS BRT (2003) reported geometric mean natural spawner counts (most recent 5 years; 1997-2001) median population growth rates (λ) for selected naturally spawning populations of Chinook in Puget Sound. Among these was the Cedar River. Short-term λ was defined as calculated from data from 1990 to the most recent year of data, with a minimum of 10 data points in the 13-year span. Long-term λ was defined as that calculated from all existing data. Both long-and short-term λ were estimated under two scenarios: one assuming that the reproductive success of naturally-spawning hatchery fish was 0 (H0) and one that it was equivalent to that of wild fish. As shown in the Table 2, all four estimates of λ for Cedar River Chinook indicate they have not been replacing themselves. Long- and short-term median population growth rates under the scenario where reproductive success of naturally spawning hatchery fish was negligible were 0.966 and 0.933, respectively; long- and short-term median population growth rates under the scenario where reproductive success of naturally spawning hatchery fish was 100% were 0.966 and 0.933, respectively. A population trajectory in which the spawners are not replacing themselves must be reverse or the populations will become extinct.

5.1.3 Diversity

Cedar River Chinook salmon exhibit an ocean-type life history, spending less than a year in freshwater before migrating to the ocean for one to fours years (average two to three years) before returning to spawn. The major form of life history diversity involves what are called fry versus fingerling migrants. Fry migrants emerge from the gravel from January through April, and within days move downstream to Lake Washington, where they rear in shoreline and small creek mouth habitats until about June. In contrast, fingerling migrants emerge between January and April, but continue to rear in riverine habitat until they migrate to Lake Washington in late spring and early summer. For the purposes of Ecosystem Diagnosis and Treatment (EDT) model runs, the WRIA 8 Technical Committee assumed 75% fry migrants and 25% fingerling or smolt migrants

Although it is highly likely that loss and modification of habitat has altered the expression of more diverse life histories of ocean-type Chinook salmon in the Cedar River, there are virtually no data to either support or refute this. Moreover, whether the Cedar River ever supported a stream-type spring Chinook population has been the subject of considerable speculation, and again there is only anecdotal historical information from which to work.

5.1.4 Spatial distribution

Adult spawning in the Cedar River peaks in October and is concentrated in the mainstem between RM 14-18; few fish spawn below RM 5 (Burton 2003). However, with the modification of Landsburg Dam to allow fish passage beginning in the fall of 2003, the spawning distribution is expected to expand along the mainstem of the Cedar River. It should be noted, however, that while the habitat above Landsburg Dam is in good condition, it is also steeper and higher in elevation (and hence cooler) and may not be as productive as the lower river.

The habitats used by juvenile Chinook salmon vary depending on the overall life history strategy. Fry migrants use shallow shoreline areas and creek mouths in Lake Washington; whereas, fingerling migrants use edge habitat in the mainstem Cedar River. The fingerling migrants tend to occupy lower gradient, side channels of the lower reaches of the mainstem and tributaries. The protection and restoration of these habitats, along with recolonization of the upper subwatershed should reverse the downward trend habitat availability and increase the life history and genetic diversity, as well as spatial distribution.

5.2 North Lake Washington

The North Lake Washington Tributaries watershed includes Bear, Cottage, Little Bear, North, Swamp, Kelsey, Evans, McAleer, Juanita, Thornton, May, and Coal creeks. Based on limited spawner surveys, about 90% of the Chinook salmon spawning in the

NLW tributaries spawn in Bear Creek.

5.2.1 Abundance

Based on the return years 1997 – 2001, the NMFS BRT (2003) reported a 5-year geometric mean abundance of natural spawning Chinook salmon in the NLW tributaries of 251. A recent calculation based on the return years 1998 – 2002 yields a geometric mean abundance of 331. While this suggests an increase in abundance, even the larger number is low enough to represent a significant risk to the population.

5.2.2 Productivity

The NMFS BRT (2003) reported geometric mean natural spawner counts (most recent 5 years; 1997-2001) median population growth rates (λ) for selected naturally spawning populations of Chinook in Puget Sound. Among these was the North Lake Washington Tributaries. Short-term λ was defined as calculated from data from 1990 to the most recent year of data, with a minimum of 10 data points in the 13-year span. Long-term λ was defined as that calculated from all existing data. Both long-and short-term λ were estimated under two scenarios: one assuming that the reproductive success of naturally-spawning hatchery fish was 0 (H0) and one that it was equivalent to that of wild fish. As shown in the Table 2, all four estimates of λ for North Lake Washington Chinook indicate they are barely replacing themselves. Long- and short-term median population growth rates under the scenario where reproductive success of naturally spawning hatchery fish was negligible were 0.995 and 1.077, respectively; long- and short-term median population growth rates under the scenario where reproductive success of naturally spawning hatchery fish was 100% were 0.995 and 1.077, respectively. Although not in as steep a decline as the Cedar River population, the life cycle productivity of the North Lake Washington population needs to increase for the abundance to grow and the recolonization the many vacant habitats in this watershed.

5.2.3 Diversity

It is believed that historically at least two life histories were present in the NLW tributaries Chinook population: an early fry migrant and a later fingerling or smolt migrant. Both forms exist today, and the proportion varies substantially for year-to-year.

Based smolt trapping studies in Bear Creek (Seiler per comm.) reported fry and smolt migrant percentages as follows:

Broodyear	Percentage fry migrants	Percentage smolt migrants
1998	12	88
1999	44	56
2000	5	95
2001	26	74
2002	4	96

5.2.4 Spatial Distribution

The spatial distribution of NLW tributary Chinook salmon is considerably reduced compared what historically existed. Approximately 90% of the returning Chinook spawn in Bear Creek, whereas historically they may have been more evenly distributed in Bear, North, Little Bear, and Swamp creeks. While this has been at least partially attributable to loss of spawning habitat, it is also a reflection of an overall reduction in productivity and the low numbers of returning adults. Improving productivity would likely make a major contribution to reversing this limited distribution of production in the North Lake Washington tributaries.

5.3 Issaquah Creek

The Issaquah Creek watershed includes, in addition to Issaquah Creek, tributaries to Lake Sammamish including Fifteenmile, McDonald, East Fork Issaquah, Lewis, Laughing, and Jacobs creeks. Chinook salmon currently spawn in Issaquah Creek in the vicinity of the hatchery and the East Fork of Issaquah Creek.

As noted above the Issaquah Creek population is a special case that is problematic when viewed through the ESA and VSP lenses. This is due to the fact that the Issaquah

Creek population is a hatchery population that originated with Green River Chinook salmon stock in 1937, with egg transfers as recent as 1992 (HSRG 2004). The natural spawning portion of this population is composed of fish returning to Issaquah Creek that are considered excess to hatchery needs (typically about 1600 fish are needed as broodstock), some of which are returned to the river to spawn upstream of the hatchery weir (others are sold as excess pet food processors, used in stream nutrient enhancement projects, or disposed of in a landfill). In the past five years the numbers released to spawn were in the thousands.

6 RISKS TO VSP IN WRIA 8 AND ASSOCIATED CONSERVATION HYPOTHESES

6.1 Cedar River

Based on a review of the status of Cedar River Chinook salmon relative to the four VSP parameters, the WRIA 8 Technical Committee characterized VSP risks as follows:

	Abundance	Productivity	Diversity	Spatial Distribution
Relative Risk	High	High	Moderate	Low

These conclusions were based on the fact that abundance is in steep decline, driven primarily by a reduction in habitat productivity and loss of life history diversity. Moreover, recent empirical data indicate a large proportion of the fish on the spawning grounds are of hatchery origin. The degradation of habitat has not only marked reduced productivity, but has greatly limited in-stream rearing capacity and reduced the proportion of juvenile using the fingerling migration trajectory.

Based on these findings, the WRIA 8 Technical Committee concluded that 1) all population attributes require restoration if the Cedar River Chinook population is to be viable; and 2) that of the four population attributes, the greatest risk comes from reduction in habitat productivity and potential loss of the in-stream juvenile rearing life history.

6.2 North Lake Washington

Based on a review of the status of the NLW tributary Chinook population relative to the four VSP parameters, the WRIA 8 Technical Committee characterized VSP risks as follows:

	Abundance	Productivity	Diversity	Spatial Distribution
Relative Risk	High	High	Moderate-High	High

These conclusions were based on an exceeding small population size, driven primarily by reduced productivity and contraction of spatial distribution. The reduced productivity is attributed to habitat degradation throughout the basin. While it was believed that relatively equal sized spawning aggregations were regularly found in 4 or more tributaries, today 90% of the returning fish spawn in Bear Creek. Here, as in the Cedar River, a high proportion of the returning fish are hatchery strays.

6.3 Issaquah Creek

As noted above, it is meaningless to apply VSP guidelines to a hatchery population or to attempt to identify risks. Abundance is to a large extent “adjustable” based on numbers of smolts produced; early life history survival and productivity is (by design) very high; genetic diversity will always be limited by hatchery broodstock management practices; and spatial distribution is, of course, limited to the hatchery rearing facilities. Perhaps more appropriate is a brief summary of the risks that hatcheries stocks pose to naturally-spawning stocks. To the extent that Issaquah Creek hatchery fish are straying and spawning with naturally reproducing population in WRIA 8 and elsewhere these risks would be relevant.

Although there have been many summary documents written on the genetic and ecological interactions of hatchery and natural salmon, one of the more concise was published by Myers et al. (2004). Very briefly, hatchery bred salmonids are subject to domestication effects and quickly become adapted to the hatchery environment – and maladapted to the natural environment. When released they tend survival at a lower rate than their naturally-produced counterparts, but still compete for food and space. Moreover, there is the potential for transmission of disease organisms that are common in hatchery environments to naturally-produced fish. In addition, returning hatchery fish tend to stray at a higher rate than naturally-produced fish and when they do stray and spawn naturally (either with other strays or with naturally-produced fish) the survival of the progeny is typically depressed. Finally, returning hatchery fish that stray onto natural spawning grounds and intermingle with natural stocks can mask the decline naturally-spawning populations.

These problems are by no means limited to the Issaquah Creek Hatchery Program, nor is there any direct evidence that each and every one of these problems is associated with this program. However, it is known that straying of hatchery fish throughout WRIA 8 is common and is a rapidly expanding phenomenon. Recent estimates are that greater than 50% of the returning Chinook salmon found in spawning ground surveys are of hatchery origin. This is obviously a situation that deserves serious attention, and will need to be addressed on a Puget Sound basin-wide scale.

7 LINKAGES AMONG WRIA 8 PRESERVATION AND RESTORATION HYPOTHESES, RISKS AND VSP

Making an explicit connection between the protection and restoration measures identified using EDT and potential changes in the VSP parameters (and hence reduced extinction risk), is a potentially important step in recovery planning. While it is one thing to use a scientific model such as EDT to diagnose “what’s wrong” and use the same tool to evaluate different “treatment options” (i.e., restoration actions), it is a more powerful strategy to use a different (and hence less- or differently-biased) approach to accomplish this function. Recognizing the importance of making this connection as a means of “closing-the-loop” the WRIA 8 Technical Committee developed a matrix linking the EDT derived actions to putative changes in the VSP parameters. The matrix is shown in Table 5.

Although such an approach is qualitative and arguably subjective, it is perhaps no less subjective than the application of “rules” in a scientific model that derived by expert opinion. It too is the product of expert opinion. Moreover, the value of this type of qualitative analyses is as much a mechanism for forcing the conservation planner to explicitly consider several key questions: What are the greatest risks to a population? What is the expected effect of the proposed conservation actions? And lastly, do the proposed actions target those risks? While this may see obvious, it is often not explicitly addressed. After all is said and done, the ability to decrease risk – risk that is associated with low abundance, reduced life-cycle productivity, low genetic diversity and limited spatial distribution – is the ultimate test of an effective recovery and conservation plan.

Inspection of Table 5 reveals that a large proportion of the proposed restoration and recovery actions are expected to affect productivity and abundance, while a much smaller proportion are expected to effect changes in diversity or spatial distribution. This is not surprising in that actions that target abundance and productivity typically are more directly influence by a broad array of activities that enhance quality of existing habitat -- including those targeting riparian health, water quality, food supply, sediment processes, refugia, abundance of predators, etc. This contrasts with the linked population parameters of genetic diversity and spatial structure which are typically affected most by those that open up new habitat, reconnect existing habitats that have been blocked or lost, and create new niches within existing habitat. In urbanized settings such as WRIA 8 much of conservation opportunity focuses on protecting and restoring habitat quality.

Categorizing actions in the way (although obviously not quantitative or precision), affords the opportunity to evaluate whether the actions selected will in fact address the population parameters judged to be contributing most to extinction risk. In the case of the Cedar River, where risks associated with abundance and productivity was judged by the Technical Committee to be high, the actions line up well. Every one of the conservation hypotheses identified would be expected to improve productivity, and hence abundance. In addition, several of the conservation hypotheses would be expected to affect diversity and spatial distribution, which were judged to be moderate and low risk parameters, respectively. It is also interesting to note that perhaps one of the most robust conservation hypotheses -- one that is expected to most profoundly affect all four VSP parameters – involves stream flows and hydrological continuity to enhance upstream migration and spawning. In an urban planning environment this will be perhaps one of the greatest challenges.

In the case of the North Lake Washington tributaries, the risks to abundance, productivity, and spatial distribution were judged by the Technical Committee to be high; and the risk to diversity was judged moderate-high. As was the case with the conservation hypotheses identified for the Cedar River, the North Lake Washington actions are heavy focused on abundance and productivity. Few, if any are expected to directly affect diversity and spatial distribution. While this at first might seem problematic, it may only be a limitation of the simplifying assumptions used to link actions and their probably effects in these watersheds. It is generally held that adult salmon tend to occupy the best (i.e., highest quality) habitats first, and begin to expand into adjacent habitat when the preferred areas are "full." To the extent that the exceptionally low numbers of adults returning to the Northlake Washington Tributaries are a factor in the concentration of spawning in Bear Creek, virtually all the measures that target increasing productivity and abundance would also be expected to extend spawning to the remaining tributaries. Such an expansion of spawning distribution would have a profound effect on spatial distribution and diversity.

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Table 1. Habitat changes that promote improvements in the VSP parameters				
	Population Size (Abundance)	**Population Growth Rate (Productivity)**	**Spatial Structure**	**Diversity**
Overall Goal	Produce more fish	Improve survival rates among one or more life stages in order to lead to higher overall population productivity	Expand areas of salmon distributions in watershed	Increase genetic and life history diversity
Specific Habitat Attribute Changes	More spawning area More rearing area Improved spawning habitat quality Improved rearing habitat quality	Keys to promoting egg incubation survival • no siltation • no burial • no scour • no desiccation • favorable water flow/oxygenation conditions • reduce/minimize egg predation Keys to promoting freshwater rearing survival • predator refuge habitat • abundant prey resources • high flow refuge habitat to avoid being swept out • competition refuge habitat • favorable temperatures Keys to promoting overwintering survival • access to off-channel habitat • access to low energy habitat • adequate flows – no stranding, not swept out • available prey resources • predator refuge habitat Keys to promoting outmigration/smoltification survival • extended salinity transition zone • flow and habitat access to move between higher and lower salinity areas • predator refuge habitat • abundant prey resources Keys to promoting nearshore survival • predator refuge habitat • abundant prey resources • extended salinity transition zone • access to suitable habitat along migration corridor • refuge from high energy conditions Keys to promoting marine/ocean survival • abundant prey resources Keys to promoting adult spawning migration survival • suitable temperatures • suitable flows for migration • expanded spawning habitat (quantity and quality) • minimize pre-spawn mortality • minimize anthropogenic increases to migration energy demands, such as partial barriers • reduce predation risks	Keys to promoting expanded spawning areas • remove full barriers (e.g., dams) • remove ecological barriers (e.g., inadequate flows, high temperatures, low dissolved oxygen • minimize anthropogenic increases to migration energy demands, such as partial barriers • suitable spawning flows providing appropriate depth and velocity • provide suitable spawning material Keys to promoting expanded rearing areas • suitable flows for access and exit (no stranding) • reduce/minimize "predation survival bottlenecks" (i.e., areas of high vulnerability to predators that lead to reduced recruitment from portions of the watershed) • suitable rearing flows providing appropriate depth and velocity	• expanded spatial structure which can extend time in river • accessibility of rearing habitat (see features in population growth rate section) that may promote fish staying in the river longer • absence of sweeping flows that send fish out to estuary (or out of areas with decent habitat) before intentional/directed movement by fish • availability of refuge habitat to avoid sweeping flows • favorable conditions for very early, peak, and very late fish in each life stage to promote extended periodicities

Table 2. Summary of abundance and life cycle productivity of WRIA 8 populations relative to VSP

	Geometric mean natural spawners (recent 5 years)	**LT λ (H0) (CI)**	**LT λ (H1) (CI)**	**ST λ (H0) (CI)**	**ST λ (H1) (CI)**
Cedar River	244	0.966 (0.861-1.085)	0.964 (0.870-1.067)	0.933 (0.843-1.058)	0.933 (0.828-1.051)
North Lake Washington Tributaries	251	0.995 (0.854-1.159)	0.995 (0.874-1.08)	1.077 (0.831-1.048)	1.077 (0..92-1.1.259)

Table 3. Generalized life histories of Chinook salmon in WRIA 8*

	Fry Migrants	Fingerling Migrants	Smolts	Adult Returns and Spawning
North Lake Washington Tributaries	Outmigrate either as fry or fingerling/smolts to Lake Washington from February to June, rearing during migration, and entering lake larger than Cedar River fry migrants.		Move offshore and enter saltwater between May and July	Spawn in northern Lake Washington Tributaries andbetween September and November.
Cedar River	Emerge between January and April, outmigrate within days of emergence to Lake Washington from February to June, rearing in shallow habitats and small creek mouths	Emerge between January and April and rear in the river; outmigrate to Lake Washington in late spring, early summer	Move offshore and enter saltwater between May and July.	Return from June- September; spawn in Cedar River and tributaries between August and November
Issaquah Creek	Migrate from tributaries to Lake Sammamish to the lake as fry or fingerlings, rearing as they migrate toward Lake Washington and enter the lake at a large size and quickly moving offshore.		Move offshore and enter saltwater between May and July.	Composed of both naturally-spawned and hatchery fish. Spawn in tributaries to Lake Sammamish, hatchery spawning between September and November

*information from WRIA 8 Draft Framework and Preliminary Actions List Document

Table 4. Known Spawning Distribution of Chinook Salmon in WRIA 8*

North Lake Washington Tributaries	Location: Bear, Cottage, Little Bear, North, Swamp, Kelsey, Evans, McAleer, Juanita, Thornton, May, and Coal Creeks. Notes: Spawning occurs primarily in Bear Creek (90%)
Cedar River	Location: Mainstem Cedar River, Taylor/Downs Creek, Peterson Creek, lower Rock Creek, and Walsh Lake Diversion Ditch; Madsen and Molasses Creeks Notes: Spawning peaks in October. Highest abundance in river miles (RM) 14-18. Few fish spawn below RM 5 (Burton 2003).
Issaquah Creek	Location: Tributaries to Lake Sammamish, Issaquah Creek, Fifteenmile, McDonald, East Fork Issaquah, North Fork Issaquah, Lewis, and Laughing Jacobs Creeks. Notes: Natural and artificial spawning occurs at the Issaquah hatchery.

*information from WRIA 8 Draft Framework and Preliminary Actions List Document

Table 5. Viable salmonid population parameters influenced by the WRIA 8 restoration and protection recommendations

Area	Draft Conservation Hypothesis	Viable Salmonid Population Parameters				
		Abundance	Productivity	Diversity	Spatial Distribution	Comments
Cedar River Mainstem	Restore riparian vegetation to provide sources of LWD that can contribute to the creation of pool habitat.	✓	✓✓	✓		Enhanced food supply and habitat complexity support higher productivity and diversity
	Restore floodplain connectivity through setback or removal of dikes and levees, the addition of LWD to create pools, and planting riparian vegetation.	✓	✓✓	✓	✓	Enhanced habitat complexity and capacity associated with levee and dike removal enhances spatial distribution, diversity and productivity
	Protect water quality to prevent adverse impacts to key life stages from fine sediments, metals (both in sediments and in water), and high temperatures.	✓	✓✓			Clean water and sediments contribute to enhanced productivity and survival
	Minimize occurrence of road crossings to maintain floodplain connectivity.	✓	✓✓			Floodplain connectivity enhances water quality and quantity which enhance productivity
	Provide adequate stream flow to allow upstream migration and spawning by establishing in-stream flow levels, enforcing water right compliance, and providing for hydrological continuity.	✓	✓	✓✓	✓✓	Enhanced base flows are a key to expanding spawning and rearing habitat, and increasing spatial distribution and diversity
	Protect forest cover throughout each of the sub-areas to maintain watershed function and hydrologic integrity (especially maintenance of sufficient base flows), and protect water quality.	✓	✓✓			Cool, clean water is a prerequisite for high productivity
	Protect pool habitat and habitat features that support the creation of pools (LWD, riparian function, and channel connectivity).	✓	✓✓	✓		Enhanced pool habitat and habitat complexity enhance productivity and diversity
South Lake Washin gton	Reduce bank hardening by replacing bulkheads and riprap with gently sloped, sandy beaches.	✓	✓✓			Unprotected banks allow natural processes which create habitat complexity and enhanced productivity

Area	Draft Conservation Hypothesis	Viable Salmonid Population Parameters				Comments
		Abundance	Productivity	Diversity	Spatial Distribution	
	Reconnect and enhance small creek mouths as rearing areas.	✓	✓	✓	✓✓	Opening up new spawning and rearing habitat is a key to enhancing spatial distribution and diversity, leading to increase productivity
	Restore overhanging riparian vegetation.	✓	✓✓			Enhanced overhanging vegetation enhances food supply and cools water, both important to enhanced productivity
	Reduce impact of docks to promote safe juvenile salmon migration and deter the aggregation of predators	✓	✓✓			Reduced predation increases early life stage survival and productivity
	Address predation effects at the mouth of the Cedar River and backwater area in lower Cedar River	✓	✓✓			Reduced predation increases early life stage survival and productivity
	Reduce pollution and contamination inputs from marinas and industrial areas.	✓	✓✓			Clean water and sediments contribute to enhanced productivity and survival
North Lake Washington Tributaries	Reduce pollution and contaminant inputs.	✓	✓✓			Clean water and sediments contribute to enhanced productivity and survival
	Reduce sediment inputs from bed scouring high flows.	✓	✓✓			Controlling bed scouring flows prevents destruction of spawning habitat and enhances productivity
	Restore riparian areas to provide future sources of LWD that can improve channel stability and contribute to pool habitat creation, and reduce peak water temperatures.	✓	✓✓			Enhanced food supply and habitat complexity support high productivity
	Protect groundwater recharge sources to Cold Creek and their connection to Cottage Lake Creek and Lower Bear Creek.	✓	✓✓			Clean water and adequate flow support enhanced productivity
	Address channel confinement in Cottage Lake Creek and Lower Bear Creek.	✓	✓✓			Unrestrained channels allow natural processes which create habitat complexity and enhanced productivity

Area	Draft Conservation Hypothesis	Viable Salmonid Population Parameters				
		Abundance	Productivity	Diversity	Spatial Distribution	Comments
	Protect water quality to prevent adverse impacts to key life stages from fine sediments, metals (both in sediments and in water), and high temperatures.	✓	✓✓			Clean water and sediments contribute to enhanced productivity and survival

TECHNICAL APPENDIX C-2

WATERSHED EVALUATION AND IDENTIFICATION OF CHINOOK SALMON TIER 1, 2, AND 3 SUBBASINS SUPPORTING SALMON CONSERVATION PLANNING IN WRIA 8

Prepared for:

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Introduction

The goal of the watershed evaluation, as part of the WRIA 8 technical committee's Strategic Assessment, is to develop an hypothesis for relative watershed function based on an evaluation of the differences that exist among WRIA 8 tributary subbasins for select landscape level indicators. Landscape scale indicators have been shown to be associated with watershed processes affecting aquatic habitat conditions in streams and rivers (e.g. May et al. 1997) of the Puget Sound lowland ecoregion. For example, in urbanizing areas the amount of impervious surfaces in a watershed has been used as a predictor of the extent to which instream flow (frequency, duration, magnitude, and/or timing) has changed (e.g., Skagit Watershed Council 2000). Altered hydrology and the characterization of those changes has been tied more explicitly to changes in stream morphology (Booth 1990), instream habitat conditions (e.g. May et al. 1997), and fish populations (Lucchetti and Fuerstenberg 1993, Moscrip and Montgomery 1997), but this level of detail and biological investigation is not within the scope of this watershed evaluation. Instead, an hypothesis of watershed condition based on landscape indicators is proposed and tested (to develop a model) with stream habitat and biological data from independent investigations and tributary stream reach specific habitat attributes coded in the WRIA 8 Ecosystem Diagnosis and Treatment (EDT) model. Additionally, as part of this evaluation, the level of use (principally for spawning) by Chinook salmon is used to develop subbasin tiers in order to propose and apply strategies for subbasin tiers and priorities for actions among tributary subbasins for each of the Chinook salmon populations bearing in mind potential future risk within this conservation geography.

An objective of the watershed evaluation is to develop an index of landscape- and riparian-scale indicators reflective of factors that contribute to the degradation of aquatic habitat conditions (Impact factors) and those indicators that can mitigate or buffer impacts (Mitigative factors) (Horner et al. 2002). Land development (e.g., houses, landscaping, clearing, agricultural activity, roads, piers, gravel mining, bridge building, filling, bank armoring, bulk-heading) can significantly alter the natural watershed processes and habitat structures to which salmonids are adapted. Depending on the type of habitat affected, biological consequences may result from changes in the quantity and quality of spawning, rearing, migration, and refuge habitats, availability and quality of food, greater exposure to predators and increased competitive interactions.

Development in riparian areas and floodplains affects aquatic areas when it removes or modifies native forest vegetation, or when it alters rates and patterns of bank and channel erosion, migration, surface, and groundwater flow. Riparian areas provide a variety of functions including shade, temperature control, water purification, woody debris recruitment, sediment delivery, terrestrial-based food supply, and channel, bank and beach erosion (Gregory et al. 1991; Naiman and Bilby 1998; Spence et al.1996). These are potentially affected when riparian and floodplain development occurs (Waters 1995; Stewart et al. 2001; Lee et al. 2001). Bolton and Shellberg (2001) provide an extensive discussion of the effects of riparian and floodplain development on aquatic habitats and species. Effects include:

- A reduction in amount, complexity, and connectivity of habitat within floodplain and riparian corridors from clearing, utilities, and increasing road crossings (May et al. 1997; Alberti et al. in press);
- Increased scouring of channels due to channel and floodplain confinement (May et al. 1997) that further isolates the river from its floodplain;
- A reduction or loss of channel migration, natural vegetation (an increase in invasive species), sediment supply; and
- A reduction or loss of woody debris recruitment (Maser et al. 1988; Bilby and Ward, 1991).

Human activities in riparian and floodplain areas have adverse impacts on LWD abundance, distribution, and function (Maser et al. 1988; Bilby and Ward, 1991). Even if LWD is not directly removed from streams in conjunction with forestry, agricultural, transportation or urbanization activities, for example, the quantity and quality of LWD diminishes over time because impacted or urbanized riparian zones can not provide LWD at normative levels (Maser et al. 1988; May et al. 1997). Recovery of LWD recruitment potential to natural levels can take many decades (Maser et al. 1988; Bisson et al, 1987; Bilby and Ward, 1989).

The fragmentation of riparian corridor continuity also impacts the functional quality of riparian and floodplain areas and has direct consequences for the quality and quantity of aquatic habitats (May et al. 1997). Road and utility crossings, land clearing, filling and encroachment from urban development in floodplain and riparian corridors effectively reduce buffer functions, alter hydrologic pathways, often directly discharge pollutants from drainage networks and fragment high quality patches of habitat (May et al. 1997; Alberti et al. in press). Importantly, these conditions in floodplains and riparian corridors have been strongly correlated with measures of ecological health, such as the B-IBI (Morley and Karr 2002; Alberti et al. in press;). Taken together, riparian corridor width, connectivity, riparian forest maturity, natural forest and wetland land cover, floodplain interactions, and vegetation type have been used to describe riparian integrity for streams in the Puget Sound region (Horner et al. 2002). Based on this approach, an index of riparian integrity has been developed that may be useful for characterizing existing conditions based on impacts from land development, identifying targets for restoration, establishing a monitoring context for riparian and floodplain areas, and for incorporating into modeling efforts such that the variability in indicators of ecological health (such as the B-IBI) can be evaluated based on riparian and floodplain conditions and functions. An extension of this approach is to evaluate how development that occurs at the landscape scale may affect aquatic areas.

Development that occurs at the landscape scale has the potential to affect aquatic habitats primarily by modifying water storage and runoff patterns and sediment erosion and delivery rates (Harr et al. 1975; Hicks et al. 1991; Booth 1990; Booth and Reinelt 1993; Booth and Jackson 1997; Booth and Henshaw 2001; Booth et al. 2002). Booth and Reinelt (1993) suggested that at a level of 10 percent effective impervious area, demonstrable, and probably irreversible, loss of aquatic system function occurs in western Washington streams. They and May et al. (1997) also noted that detrimental effects on channel conditions or habitat quality were evident well before 10 percent was reached and that no “threshold of effect” attributable to impervious area was observed. However, this likely has as much to do with a dramatic decrease in forested land cover at the watershed scale and within riparian corridors as it does with the increase in impervious area up to 10 percent (Figure 1 showing subbasin values from WRIAs 5,7, and 8 from data by Purser et al. (2003)). In fact, the relationship between impervious area and forest cover is strikingly discontinuous up to and above approximately 10 percent impervious area. Thus the change in TIA up to 10% represents a poor surrogate for the stronger agent of change, loss in forest cover. Given this conclusion, models developed to explain the variability in aquatic habitat conditions or biological response (e.g., B-IBI) should incorporate both forest cover and impervious area among other factors (Horner et al. 2002). For example, Alberti et al. (in press) reported significant positive correlation between percent subbasin forest cover and instream biotic integrity.

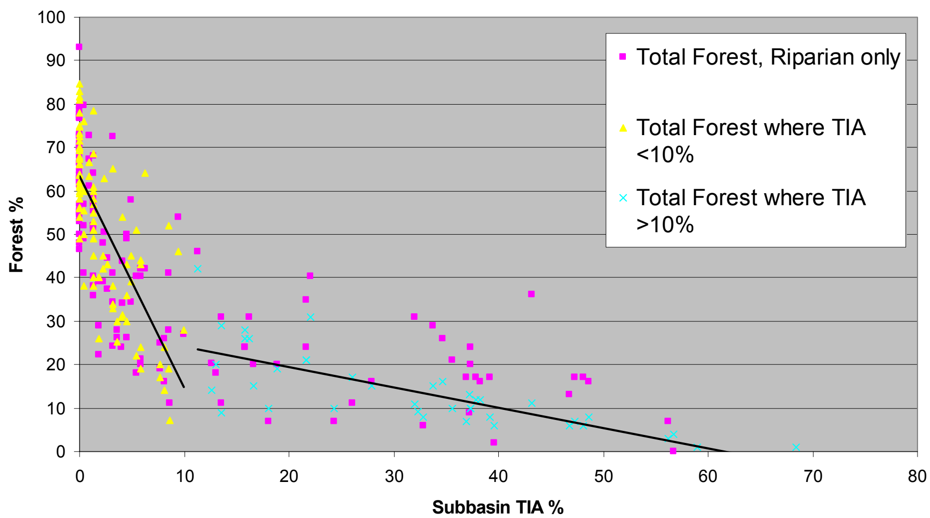

Figure 1. The relationship between subbasin total impervious area (TIA) and subbasin and riparian total forested land covers in WRIAs 5,7, and 8.

In developing an index to quantitatively stratify subbasins by impact and mitigative factors, and bin subbasins within impact or mitigative classes, an hypothesis of habitat function as determined by watershed condition is proposed. This assessment is detailed below in individual steps of this approach. Finally, in addition to assessing relative differences that exist among watershed indicators and Chinook salmon use, the subbasin- and near-stream (≈275 ft) extent of change in estimated total impervious area (TIA) and total forested land cover between 1991 and 2001 is reported in order to document the rate of change associated with these key land cover conditions and thereby frame a discussion on the potential risk of future changes that may affect individual subbasins, the population response, and thereby the conservation geography within WRIA 8. This watershed evaluation does not apply to lake habitats in WRIA 8. Strategy development and prioritization for actions based on geography and action type for lake habitats (i.e., Lakes Washington, Sammamish and Union, and the Ship Canal) is addressed primarily with the customized portion of the WRIA 8 EDT model. Other limitations and caveats associated with this watershed evaluation are covered below.

Methods and Results

Step 1. Selection of watershed indicators

The selection of watershed indicators is driven in part by the appropriateness of the indicator to scale of investigation (subbasins 7-40 km^2; Upper Cedar River is an outlier at approximately 330 km^2) and available data that is consistent across the WRIA. Additionally, the watershed indicators selected were ones that were considered primary drivers of watershed processes related to hydrologic change or indicators (such as gradient) that would interact with changes in hydrology to produce limiting habitat conditions or mitigate for those changes.

The following information resources were used to select watershed indicators;

- 1991 and 2001 land cover classification of Landsat™ imagery (Purser et al. 2003) for Total Impervious Area (TIA) estimate and total forested land cover.
- SSHIAP (Salmon and Steelhead Habitat Inventory and Assessment Project) WRIA 8 stream gradient/confinement/channel type classification (http://wdfw.wa.gov/hab/sshiap/gisdata.htm). This spatial dataset for streams was also used to buffer (by 3, 28-meter pixels) land cover grid data to determine subbasin percent near-stream (approximately 275 feet) riparian forest composition for the stream reaches overlapping with the spatial distribution of Chinook and coho salmon based on WRIA 8 fish distribution mapping (http://dnr.metrokc.gov/Wrias/8/fish-maps/distmap.htm). In the upper Cedar River, the distribution of cutthroat trout was used.
- TRI-County Biological Review database (unpublished database, pers. comm. Gino Lucchetti 1/31/2003) and database summary tables in (http://salmoninfo.org/tricounty/documents/bioappendices.pdf).
- Screening Level Analysis Of 3rd Order And Higher WRIA-8 Streams For Change In Hydrologic Regime-A Report of the WRIA-8 Technical Subcommittee on Flow Regime (as published in Kerwin 2001). The change in flow volume index was used for whole subbasin areas. In many cases these were 3rd order streams; In other cases these values were based on multiple tributary drainages. Because of their unique location in the middle of the watershed drainage network, the mainstem Sammamish River flow volume index is reported for the entire drainage area upstream (160 and 240 mi^2) and not for the smaller contributing tributaries within these subbasins (12.1 and 13.8 mi^2).

All data used were summarized by the subbasin delineation (Figure 2) from Screening Level Analysis Of 3rd Order And Higher WRIA-8 Streams For Change In Hydrologic Regime-A Report of the WRIA-8 Technical Subcommittee on Flow Regime (as published in Kerwin 2001). This subbasin delineation in some cases has problems with accurate subbasin boundaries (such as for Kelsey Creek), and in those cases the subbasin values were pooled and weighted by subbasin area.

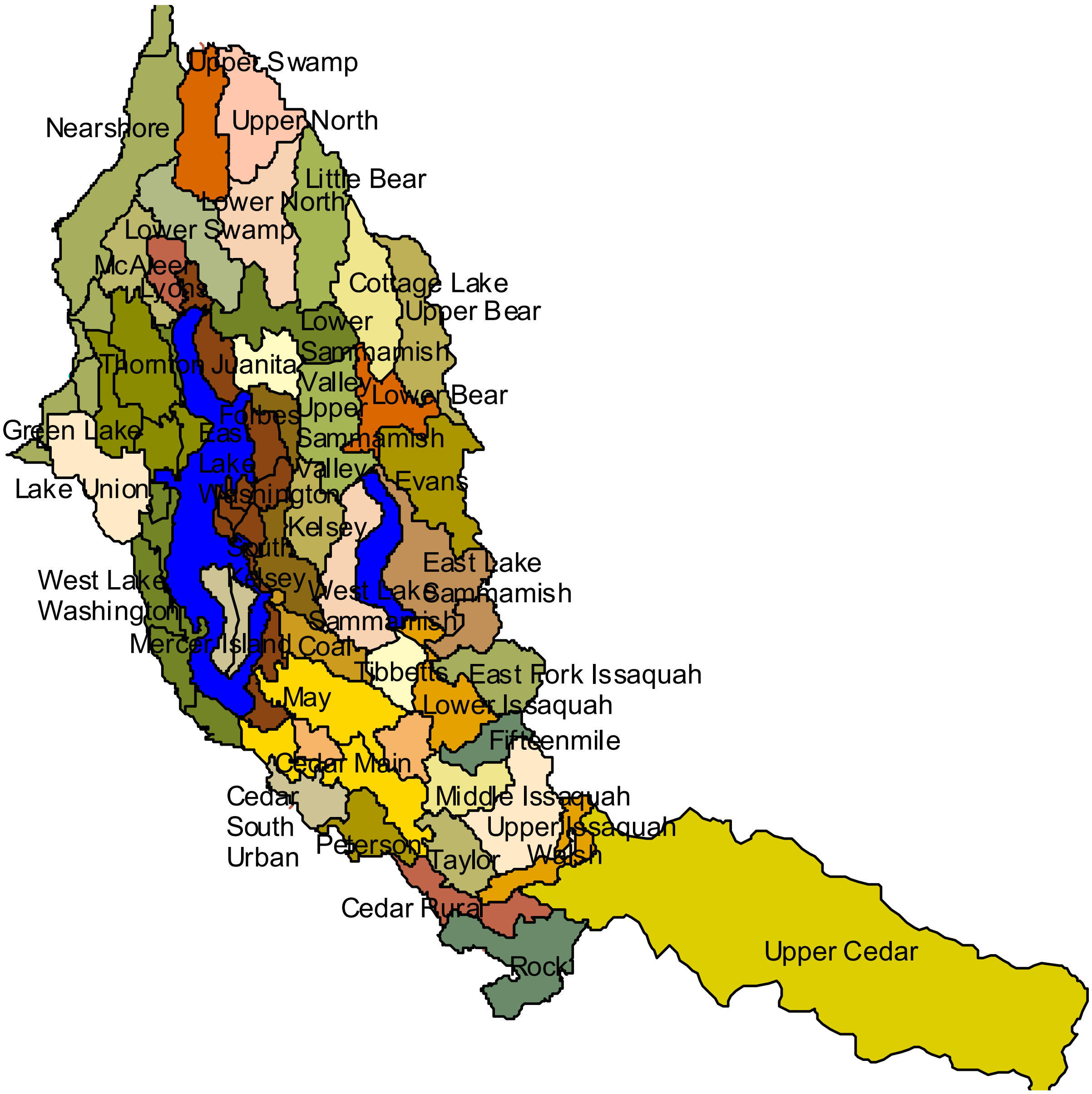

Figure 2. Subbasin delineation based on Screening Level Analysis Of 3rd Order And Higher Wria-8 Streams For Change In Hydrologic Regime-A Report of the WRIA-8 Technical Subcommittee on Flow Regime (in Kerwin 2001).

Table 1 lists the watershed indicators selected for this analysis, assumptions regarding their applicability, whether the indicator is associated with habitat impacts or is mitigative of impacts and conditions, and data source.

Table 1. Selected WRIA 8 watershed indicators.

Indicator	Factor	Assumption	Data Source
% Total impervious area	Impacting	Channel morphology, habitat conditions and biological responses have been negatively correlated with increasing amounts of TIA	Purser et al. 2003

		(e.g., Booth 1990, May et al. 1997).	
% Total forest area	Mitigative	Retention of hydrologically mature forest cover limits hydrologic alteration (Horner and May 1999).	Purser et al. 2003
% Wetland area	Mitigative	A greater proportion of wetland cover is reflective of hydrologic retention, groundwater recharge and discharge and contributes to limit hydrologic alteration as non-structural stormwater BMPs (NRC 1995; Horner et al. 2002).	Tri-County database, Gino Lucchetti, Pers. Comm. (based on USFWS, NWI)
% Riparian forest area	Mitigative	Intact riparian forests retain hydrologically connected wetlands and side channels, contribute large and small organic material, and regulate temperature and nutrient cycling, among other functions (reviewed in Spence et al 1996; Pollack and Kennard 1998).	Purser et al. 2003
Road crossing frequency (#/km)	Impacting	Road crossings directly impact riparian, wetland, and instream conditions as a result of vegetation removal, streambank armoring, bankfull width and hydraulic alteration and directly increase watershed drainage density (May et al. 1997).	Tri-County database
Storm volume change index	Impacting	This index is proposed to account for the differing contributions of surface, interflow, and groundwater discharge to elevated stream flows during and following storm events. Value contributes to stream power when interpreted with gradient.	Kerwin 2001
% Stream reaches ≥4% gradient	Impacting	Stream gradient affects stream power in combination with flow volume. A greater proportion of high gradient reaches is indicative of risk to altered sediment supply and channel degradation.	SSHIAP, data accessed 7/24/2001 from http://www.wdfw.wa.gov
% Stream reaches ≤2%, unconfined	Mitigative	Low gradient unconfined reaches are correlated with suitable conditions from pool:riffle and forced pool:riffle habitat sequences (Montgomery et al. 1999).	SSHIAP

Step 1: Selection of Habitat Indicators

Six instream and riparian habitat attributes were selected from the more than 40 stream reach specific environmental attribute input parameters required for the Ecosystem Diagnosis and Treatment model. EDT requires that input data, whether qualitative or quantitative, be coded (0,1,2,3,4) reflective of condition based on definitions ascribed to each level. Thus EDT offers a ready made organizational framework for developing a continuous habitat index applicable at the reach scale that can be used in its own right separate from (but still linked to) the EDT model. For the creation of an Environmental Attribute Index (EAI), some criteria were considered:

- Attribute codes ranging from 0-4 must describe the continuum from natural conditions (code 0) to most degraded (code 4),
- Attribute values must be variable and vary across a continuum of land use/ land cover conditions,
- Attributes will represent those with demonstrated significant effect on fish abundance, productivity, life history diversity or spatial distribution in freshwater,
- Attributes will represent those for which empirically derived observations exist, at best, and for which data input for target reaches is complete and has been reviewed satisfactorily by the WRIA 8 technical committee.

Based on the consideration of these criteria EAI constituents were Woody Debris, Temperature-maximum, Riparian condition, Fine sediment, Primary pool habitat area, and Bed Scour.

EDT reaches selected for model testing at the subbasin scale included those reaches in consideration of the following criteria;

- Reaches considered from a geomorphological stand point to be response reaches (<2% gradient with confined, moderately confined or confined floodplain morphology or 2-4% gradient with unconfined valley morphology);
- Reaches overlapping with (at a minimum) chinook salmon distribution
- Reaches for which contributing subbasin area was already delineated and land cover composition quantified.

In consideration of these criteria, 295 reaches among 595 total EDT reaches in WRIA 8 were used. Significant areas excluded from this analysis included all of Issaquah Creek and its contributing subbasins based on input data quality control and assurance, Lower Cedar River subbasins as total contributing land cover characteristics and other watershed indicators were not summarized at this larger scale, and direct drainages to Puget Sound, Lakes Washington and Sammamish including the Sammamish River proper and its contributing sidewall tributaries. Among the 42 subbasins present in WRIA 8, 26 were included in this analysis.

For all reaches, and index score was calculated based on the sum of the unweighted input codes. At the subbasin scale, reach index scores were multiplied by the reach length and the sum of all reach length weighted scores were divided by the total subbasin reach length to derive a reach length weighted index value. Of course, this approach reduces some of the range and variability in index scores associated with individual reaches that potentially could be evaluated using other scales of investigation (such as the contributing area upstream from each EDT reach), but which is beyond the scope of this analysis.

Step 2: Selection of Biological Indicators

The benthic index of biotic integrity was selected as the sole biological response for this analysis in order to test the watershed evaluation hypothesis of watershed function. For this study no new B-IBI were generated in order to specifically test the watershed evaluation hypothesis. Thus, existing B-IBI values from a range of published and unpublished sources were used. These included Morley (2000), Snohomish County (2004), and King County (Brian Murray, pers. communication, 2004). In all, B-IBI values were collected for 30 of 42 subbasins in WRIA 8. For this analysis, Issaquah Creek subbasins were included, except Lower and Middle Issaquah for which no total contributing land cover summary was available. B-IBI values selected for this analysis covered the years 1995-2003. Although the land cover data is based on a snapshot in time (August, 2001), the lack of trend detection (as an analytical exercise) in B-

IBI studies over subsequent sampling years suggest selection of data points outside of the year 2001 assumes changes are insignificant and non-detectable so as not to warrant their exclusion. For this analysis all subbasin B-IBI values regardless of year or sampling location were given equal weight. Data were summarized in terms of highest, average and lowest B-IBI score for each subbasin.

In addition to the selected watershed, habitat and biological indicators, other indicators were considered but not included in the analysis at this time due to inadequacies of data coverage, uncertainty of applicability and interpretation at the subbasin scale, or due to constraints related to hypothesis testing. These include:

- Base flow change index - from Screening Level Analysis Of 3rd Order And Higher Wria-8 Streams For Change In Hydrologic Regime. Within the WRIA 8 technical committee there was not unanimous support for using this indicator of flow change. It was suggested that surface- and ground-water exchange (recharge/discharge) contributing to base flow support be better reviewed before any applicable subbasin metric is selected.
- Road density (mi/mi^2) - not used because it is strongly correlated with subbasin TIA (May et al. 1997) and at higher density reduces the difference between effective and total impervious area because much of the drainage network is linked via roads and ditches. In rural and forested subbasins, it would be more applicable as an indicator of surficial erosion.
- Flow control BMPs - quantified as area or acre-ft retained/detained with structural BMPs (after May 1996; Horner et al. 2002)
- Hydromodifications - human-placed bank and floodplain artificial structures (such as riprap, revetments, levees, bridge crossings/footing, rail/road grades, other) disrupting floodplain, riparian and in-channel processes and habitat. Data sources are inconsistent and not available across WRIA 8.
- Patterns of fragmentation, clustering or adjacency of land cover classes within subbasins were beyond the analytical scope of this effort but may yield useful metrics for subbasin analysis.
- Direct measures of sediment supply and transport and/or landscape scale indicators of sediment supply and transport were not included. Although there are good examples of these processes being considered in less urban, forest and forestry dominated watersheds

Step 3: Identifying subbasin metric ranks for selected indicators

For this step, subbasin data for each indicator were plotted from lowest to highest value. Because each metric has its own range of potential values, each metric is given a score before it is incorporated into the final subbasin rating. Three rating criteria within the data distribution were identified based both on literature values and range and variability within the dataset so the ranks assigned would be meaningful. Next, three ranks of condition were assigned (1, 3, 5) for each indicator (Table 2) with 5 representing highest level of impact and highest level of mitigative value by indicator.

Table 2. WRIA 8 watershed evaluation rating criteria and associated index rating value for select watershed-scale indicators. Also included is the direct source for rating criteria or supporting literature.

Indicator	Rating criteria for indicator ranks			Source for rating criteria
Rating value	1	3	5	
% Total	<10%	10-30%	>30%	Based on May 1996.

impervious area				
% Total forest area	<20%	20-40%	>40%	Based on data distribution. May (1996) suggests 30%/50% break points.
% Wetland area	<3%	3-5%	>5%	Based on data distribution. This rating criteria is different from loss of wetlands
% Riparian forest area	<20%	20-40%	>40%	Note: this is based on 90 m buffer width. May (1996) sampled at 30 m width, and proposed 70% cover intact riparian forest.
Road crossing frequency,#/km	<2	2-3	>3	Based on May 1996, NOAA 2003.
Storm volume change index	<20	20-50	>50	Based on data distribution and results presented in Kerwin (2001).
% Stream reaches ≥4% gradient	<30 %	30-50%	>50 %	Based on data distribution and assumption higher proportion of high gradient reaches contributes to increased stream power.
% Stream reaches ≤2%, unconfined	<30 %	30-50	>50 %	Based on data distribution and assumption higher proportion of low gradient, unconfined reaches contributes to favorable habitat and, in part, mitigates increased peak flows and volume.

For example, Figure 3 shows metric break points (10% and 30%) for 2001 subbasin %TIA for WRIA 8. Metric break points identified based on 1991 subbasin TIA were also 10% and 30%. All impact and mitigative factor break points and figures are included as supplemental figures S1-S8.

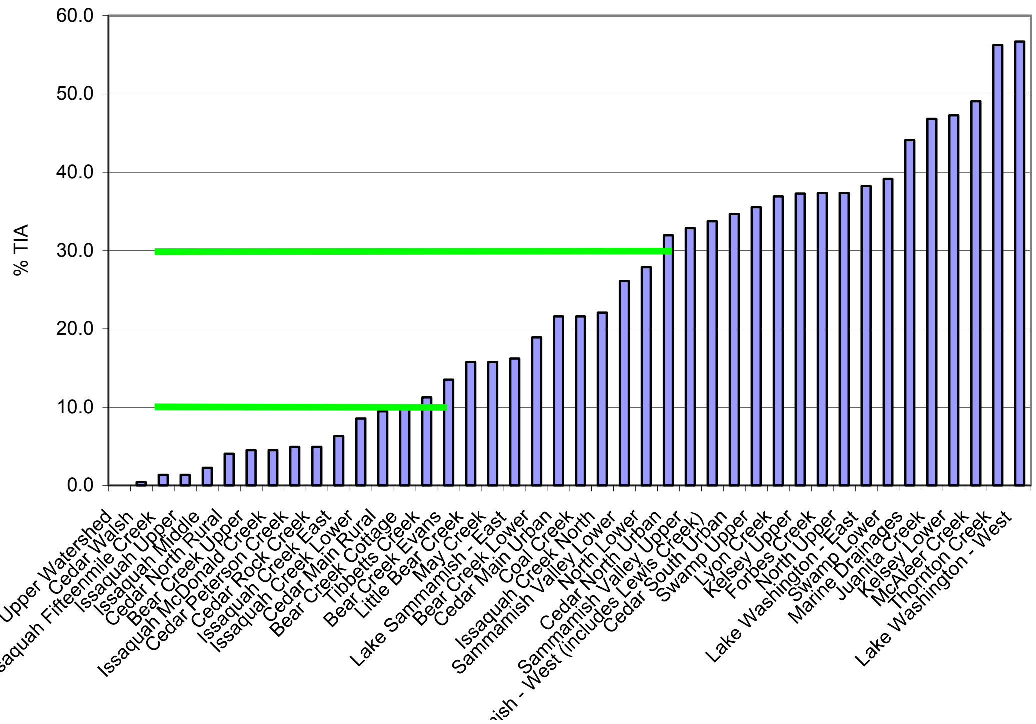

Figure 3. Example of rating criteria thresholds (10% and 30%) for subbasin %TIA and WRIA 8 subbasin distribution based on year 2001 land cover classification.

Subbasin data and metric ratings are included in Table 3. The subbasin data and metric ratings were grouped by impact factors and mitigative factors. For each group of impact and mitigative factors, metric ratings were summed. It is hypothesized that the higher the impact score the less suitable habitat conditions are expected. As well, the higher the mitigative score the more likely favorable habitat conditions can be maintained in a subbasin.

Step 4: Identifying watershed evaluation subbasin ratings.

A final subbasin rating was established by subtracting the impact sum value from the mitigative sum value. Where impact sum values are high, it is less likely mitigative attributes are widespread or effective. Where mitigative sum values are high it is more likely that impacts are isolated and mitigative factors predominate. In some cases, higher impact sum values are balanced by high mitigative sum values. These include low gradient, wetland rich subbasins with better protected riparian buffers and fewer road crossings than expected given the level of subbasin development (e.g., Upper North Creek, Evans Creek, East Lake Sammamish, Lower Kelsey Creek, Forbes Creek, and Upper Swamp Creek). These subbasins would be considered impacted and very at-risk from future degradation. Based on this approach of debiting impact factors from mitigative factors, a final subbasin score is calculated and watershed evaluation rating is proposed (Table 3). At this time, neither the impact or mitigative sum scores nor their constituent indicator metrics are weighted and the final watershed evaluation rating is based on selecting two point demarcations within the continuous distribution of subbasin scores. For the higher watershed condition, the impact sum score was < 10 and mitigative score was >12. For the lower watershed condition, the impact sum score was >14 and mitigative score was < 12. The one outlier based on this scheme is Evans Creek. There are many mitigative attributes present, but were its rating based on %TIA, Evans Creek would have a moderate watershed rating.

Step 5: Watershed Evaluation hypothesis testing.

Simply put, the watershed evaluation hypothesis is that the distribution of watershed scores and proposed ratings based on the condition of landscape level watershed indicators explains some meaningful level of habitat condition or biological response. It is further hypothesized that proposed strategies and actions for individual subbasins or tiers of subbasins can be identified based on these tested relationships between conditions and response.

The first null hypothesis tested was that watershed conditions represented by the watershed evaluation score were not correlated with habitat quality. Using regression analysis on 2 independent and continuously variable data sets, this hypothesis was rejected. Watershed condition explains approximately 67% of the observed variability in weighted subbasin habitat condition as shown in Figure 4 (where $r=0.82$, $r^2=0.67$, $p<0.0001$). The model itself appears to be satisfactory as well in terms of error variance and explanatory power along the continuum of watershed condition. The greatest outlier (x,y = 16,6) is the Walsh Lake diversion ditch, which even given its relatively intact headwaters is described as a “high gradient, high-velocity chute” (Kerwin 2001). It may be that additional explanatory value would be attained by either including additional habitat metrics or additional watershed indicators as part of the watershed evaluation such that outlier points like Walsh Lake ditch were accounted for better in the model. Additionally Lower Bear Creek is evaluated in terms of a watershed score and habitat index value weighted by the contributing subbasin areas and respective watershed scores from those areas. A more rigorous approach would have been to include the total contributing area and develop a watershed score based on this area rather than using an additive weighted approach as described. Potentially the most important factor to add would be confinement from artificial hydromodifications. Unfortunately it was determined during the course of limiting factors analysis (Kerwin 2001) for WRIA 8 that hydromodifications and streambank condition were not well documented across the watershed.

The second null hypothesis tested was that watershed conditions represented by the watershed evaluation score were not correlated with biological integrity. This hypothesis is rejected but the results were unsatisfactory (Figure 5, Full score, r=0.75, r^2=0.56, p<0.0001), given that the variability in average B-IBI was explained more completely by percent total impervious area alone (r=0.89, r^2=0.78, p=0). Upon further examination, both gradient and wetlands were temporarily removed from the watershed score as individually they contributed no explanatory value. The remaining watershed indicators formed an abbreviated watershed score (Table 3) and the variability in averaged B-IBI values was satisfactorily explained by this model (Figure 5, r=0.9, r^2=0.82, p=0).

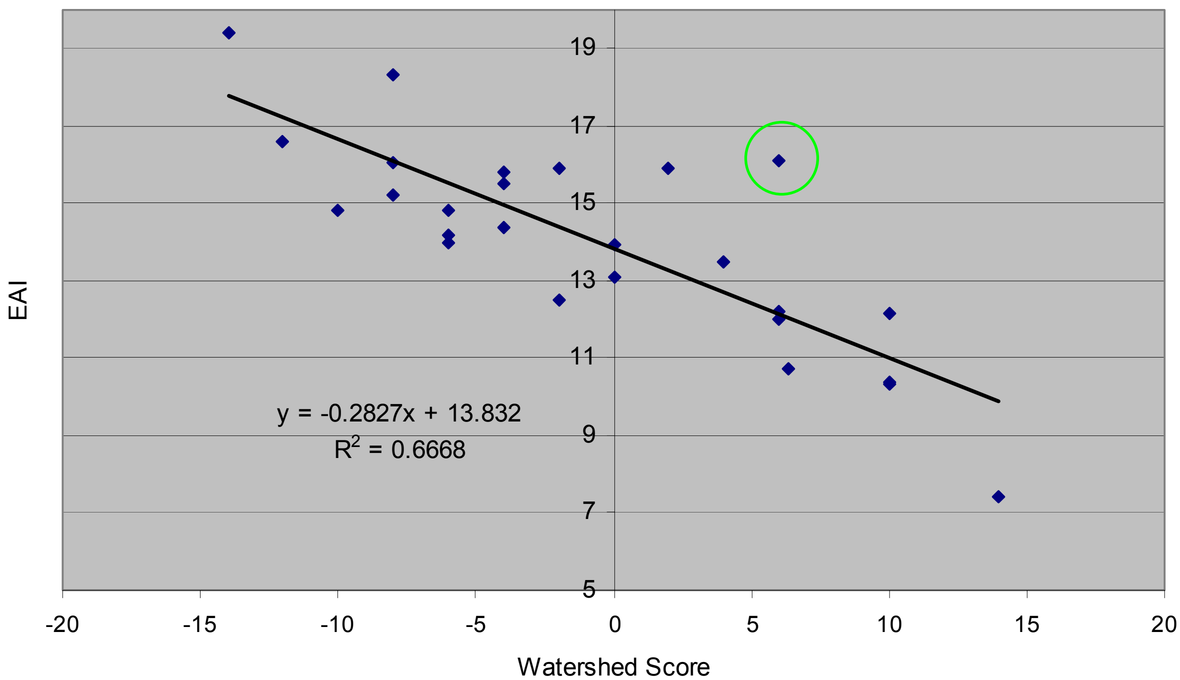

Figure 4. Environmental Attribute Index rating scores regressed against watershed evaluation scores. A higher watershed score is hypothesized to correlate with better habitat condition. Increasing EAI is reflective of increasing habitat degradation. Outlier (circled) is Walsh ditch.

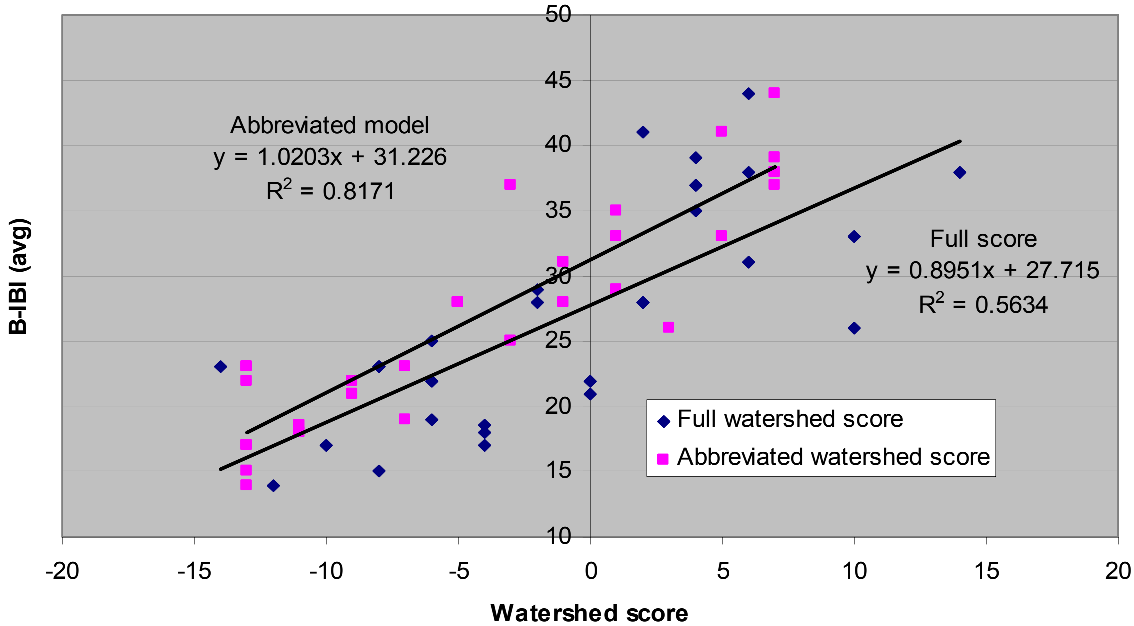

Figure 5. Subbasin averaged B-IBI scores regressed against the full watershed evaluation scores and an abbreviated version as presented in Table 3.

Table 3. Watershed evaluation subbasin impact and mitigative factor data, ratings and combined final score along with suggested relative watershed condition ratings split into three categories of function.

Subareas	Impact Factors										Mitigative Factors										Watershed Evaluation		EDT		
Spawning basins only (chinook/coho)	%TIA, 2001	%TIA rating	Flow volume change data	Flow volume change rating	Gradient >4% data	Gradient >4% rating	Road xing freq (#/km) data	Road xing freq (#/km) rating	Impact Score	Rating	Wetland area, %, NWI, data	Wetland area, %, rating	Gradient <2%, data, SSHIAP	Gradient <2% rating	% Forest cover, data	Forest cover, rating	% Riparian forest cover, data	Riparian forest cover rating	Mitigative Score	Rating	Final Score	Proposed Rating	EAI index	B-IBI, Avg.	Abbr. watershed score
Cedar Rock Creek	4.95	1	12	1	9	1	1.15	1	4	Low	3.5	3	76	5	45	5	58	5	18	High	14	High	7.4	38	7
Cedar Main Rural	9.45	1	40	3	2	1	1.15	1	6	Low	3.6	3	65	5	46	5	54	5	18	High	12	High			5
Bear Creek Cottage	9.9	1	49	3	2	1	1.89	1	6	Low	6.5	5	98	5	28	3	27	3	16	High	10	High	10.3	33	1
Bear Creek Upper	4.5	1	34	3	51	3	1.89	1	8	Low	7.9	5	46	3	43	5	49	5	18	High	10	High	12.2	33	5
Cedar Peterson Creek	4.95	1	14	1	25	1	1.15	1	4	Low	3.6	3	68	5	39	3	34	3	14	Mod	10	High	10.4	26	3
Bear Creek Evans	13.5	3	45	3	44	3	1.89	1	10	Mod	8.9	5	56	5	29	3	31	3	16	High	6	High/Mod	12.2	31	-1
Cedar Upper Watershed	0	1	14	1	82	5	1.06	1	8	Low	3.5	3	13	1	78	5	93	5	14	Mod	6	High	12.0	44	7
Cedar Walsh	0.45	1	15	1	65	5	1.15	1	8	Low	3.6	3	23	1	76	5	79	5	14	Mod	6	High	16.1	38	7
Cedar North Rural	4.05	1	39	3	46	3	1.15	1	8	Low	3.6	3	49	3	31	3	24	3	12	Mod	4	High	13.5	35	1
Issaquah Creek Lower	8.55	1	30	3	70	5	1.70	1	10	Mod	2.1	1	30	3	52	5	41	5	14	Mod	4	Mod			5
Issaquah Creek North	22.05	3	62	5	22	1	1.76	1	10	Mod	3.7	3	62	5	31	3	40	3	14	Mod	4	Mod		37	-3
Issaquah Fifteenmile Creek	1.35	1	15	1	98	5	0.87	1	8	Low	2.1	1	2	1	61	5	64	5	12	Mod	4	High		37	7
Issaquah Middle	2.25	1	28	3	47	3	1.50	1	8	Low	2.1	1	49	3	42	5	39	3	12	Mod	4	High			3
Issaquah Upper	1.35	1	16	1	81	5	0.87	1	8	Low	2.1	1	7	1	49	5	52	5	12	Mod	4	High		39	7
Lake Sammamish - East	16.2	3	45	3	32	3	2.55	3	12	Mod	6.8	5	68	5	26	3	31	3	16	High	4	Mod			-3
Bear Creek Lower	18.9	3	71	5	33	3	1.89	1	12	Mod	5.2	5	67	5	19	1	20	3	14	Mod	2	Mod	10.7	28	-5
Cedar Main Urban	21.6	3	70	5	19	1	1.15	1	10	Mod	3.6	3	81	5	21	1	24	3	12	Mod	2	Mod			-5
Issaquah Creek East	6.3	1	25	3	80	5	1.78	1	10	Mod	0.3	1	17	1	64	5	42	5	12	Low	2	Mod		41	5
Issaquah McDonald Creek	4.5	1	33	3	60	5	0.87	1	10	Mod	2.1	1	34	3	36	3	50	5	12	Mod	2	Mod			3
May Creek	15.75	3	43	3	49	3	1.65	1	10	Mod	3.2	3	49	3	28	3	24	3	12	Mod	2	Mod	15.9	28	-1
Sammamish Valley Lower	26.1	3	48	3	36	3	1.87	1	10	Mod	6.3	5	62	5	17	1	11	1	12	Mod	2	Mod			-5
Sammamish Valley Upper	32.85	5	41	3	26	1	1.87	1	10	Mod	6.3	5	74	5	8	1	6	1	12	Mod	2	Mod			-7
North Lower	27.9	3	72	5	25	1	2.25	3	12	Mod	8.2	5	71	5	15	1	16	1	12	Mod	0	Mod	13.1	21	-9
North Upper	37.35	5	84	5	25	1	2.25	3	14	Mod	8.2	5		5	10	1	24	3	14	Mod	0	Mod	13.9	22	-9
Little Bear Creek	15.75	3	61	5	41	3	2.76	3	14	Mod	2.5	1	56	5	26	3	24	3	12	Mod	-2	Mod	12.5	28	-5
Tibbetts Creek	11.25	3	25	3	74	5	2.02	3	14	Mod	1.5	1	25	1	42	5	46	5	12	Mod	-2	Mod	15.9	29	1
Forbes Creek	37.35	5	77	5	14	1	3.62	5	16	High	3.6	3	86	5	10	1	20	3	12	Mod	-4	Low	15.8	18	-11
Kelsey Lower	47.25	5	84	5	20	1	3.47	5	16	High	6.1	5	80	5	7	1	17	1	12	Mod	-4	Low	15.5	17	-13
Swamp Upper	35.55	5	76	5	11	1	3.01	5	16	High	4.4	3		5	10	1	21	3	12	Mod	-4	Low	14.4	19	-11
Cedar South Urban	34.65	5	58	5	55	5	1.15	1	16	High	3.6	3	36	3	16	1	26	3	10	Low	-6	Low	14.8	19	-7
Coal Creek	21.6	3	46	3	71	5	1.92	1	12	Mod	0.4	1	14	1	21	1	35	3	6	Low	-6	Low	14.2	25	-3
Swamp Lower	39.15	5	87	5	11	1	3.01	5	16	High	4.4	3	65	5	8	1	17	1	10	Low	-6	Low	14.0	22	-13
Cedar North Urban	31.95	5	71	5	83	5	1.15	1	16	High	3.6	3	17	1	11	1	31	3	8	Low	-8	Low	15.2	23	-7
Kelsey Upper	37.273	5	70	5	26	1	3.47	5	16	High	2.2	1	74	5	13.1313	1	9	1	8	Low	-8	Low	16.1	15	-13
McAleer Creek	49.05	5	83	5	5	1	3.61	5	16	High	2.5	1	61	5	6	1	17	1	8	Low	-8	Low	18.3	23	-13
Juanita Creek	46.8	5	83	5	40	3	5.24	5	18	High	1.7	1	60	5	6	1	13	1	8	Low	-10	Low	14.8	17	-13
Lake Washington - East	38.25	5	41	3	64	5	4.66	5	18	High	4.2	3	36	3	12	1	16	1	8	Low	-10	Low			-11
Marine Drainages	44.1	5	80	5	85	5	1.20	1	16	High	1.8	1	12	1	11	1	34	3	6	Low	-10	Low			-7
Thornton Creek	56.25	5	59	5	49	3	4.71	5	18	High	0.3	1	33	3	3	1	7	1	6	Low	-12	Low	16.6	14	-13
Lake Sammamish - West (i	33.75	5	63	5	82	5	3.88	5	20	High	1.8	1	16	1	15	1	29	3	6	Low	-14	Low			-11
Lake Washington - West	56.7	5	49	3	100	5	3.91	5	18	High	2.3	1	0	1	4	1	0	1	4	Low	-14	Low			-11
Lyon Creek	36.9	5	59	5	46	3	3.54	5	18	High	1	1	22	1	12	1	17	1	4	Low	-14	Low	19.4	23	-13

Subbasin rating is estimated

Limitations and Uncertainties
There are a number of limitations and uncertainties regarding hypothesis testing at this time. As indicated above, this evaluation applies only to subbasins that are tributary to larger rivers, lake habitats and the Puget Sound nearshore. It is not an approach or tool that captures the entire geography of the WRIA, nor does it do so at a finer spatial scale. This evaluation also includes only those subbasins that provide spawning habitat for Chinook and or coho salmon. Therefore, the Mercer Island, Green Lake, North Lake Washington, and the Lake Union subbasins were not included in this evaluation. For these subbasins, however, 1991 and 2001 land cover data are included in Tables 9 and 10.

For this evaluation of watershed condition, all metrics are reported by whole basin and near-stream (approximately 275 ft) riparian area and do not account for spatial variability in land cover or development pattern, such as clustering, fragmentation or adjacency of land cover classes. The near-stream (approximately 275 ft) riparian area used is not intended to be regarded as a “buffer” in the regulatory sense. From a spatial perspective, it made the most sense to evaluate land cover at a distance of three 28-meter pixel widths from stream locations. Because, at the same time, stream locations are rarely depicted accurately, a wider near-stream area will maximize the likelihood of describing near stream conditions without being so wide that the result tends toward the overall subbasin land cover composition.

For this evaluation of watershed condition, all metrics were treated with equal weight in terms of their contribution to determining watershed condition. In general, impact factors were selected which primarily affect the hydrologic regime and/or interact with altered hydrology to alter stream hydraulics. An alternative would be to add weight (e.g. x2) to %TIA and road crossing frequency metric ranks or to apply a weight (e.g. x2) to the final impact score (based on an assumption that impact factors associated with urbanization will overwhelm remaining subbasin mitigative factors). Weighting metric ratings may prove useful when performing alternative model fitting and parameter. In its current form, the watershed evaluation portrays relative subbasin conditions using appropriate and relevant indicators based on the watershed data distribution and criteria for metric ratings based on best available science.

Step 6. Identifying Chinook salmon use among subbasins

In addition to the watershed evaluation exercise described above, a Chinook salmon population matrix was developed in order to segregate subbasins by population use in addition to watershed condition. This approach was taken in order to develop subbasin strategies for Chinook salmon populations but still remain independent from the habitat-based EDT salmon performance model.

Population information assembled for this exercise was based on the NOAA-Fisheries Viable Salmonid Population attributes for populations; Abundance, Productivity, Spatial Distribution and Diversity (McElhany et al. 2000) and Washington State Salmon and Steelhead Stock Inventory (SASSI) (WDF et al. 1993). For each of the three Chinook salmon populations (Cedar River, North Lake Washington, and Issaquah) considered for this evaluation, the level of fish use (spawning and early rearing) within subbasins was characterized as belonging to a core group, satellite group, or episodic group. Table 4 displays the underlying data used to develop the level of fish use proposed. Definitions of core, satellite, or episodic fish use are provided in the table footnotes and information regarding the spatial distribution of populations comes from a spatial dataset (i.e. GIS) based on species observation (http://dnr.metrokc.gov/Wrias/8/fish-maps/distmap.htm). These results were also reported and used in the WRIA 8 Near-Term

Action Agenda and are summarized in Table 5, which also includes a migratory/rearing use designation assigned to some non-spawning areas (e.g., Lake Washington).

Table 4. 2003 WRIA 8 Chinook salmon population analysis matrix.

		Diversity				Abundance				Distribution					Productivity					
						PROFESSIONAL SURVEYS		OBSERVATIONS (since 1996, except Kelsey							production/ female		Mean survival ratios			
Chinook salmon population affiliation	Chinook salmon subareas	Population affiliation origin[1]	Production type[1]	Status[1]	Known minimum life history trajectories[2]	Mean adult abundance	Years of record	Mean adults observed	Incidence of chinook per years of observation	Basin Area (mi2)	BFW, min (from EDT)	Length of stream used, miles	Number of tributaries used/ length used, miles	Low gradient un-confined reaches (%)/ miles	Fry	Smolts	Fry/ egg deposited	Smolts/ egg deposited	Total %	WRIA 8 Population Designation Core/ Satellite/ Episodic[4]
Cedar	Cedar	Native	Wild	Depressed	2	746	64-66, 68-99	n/a	n/a	65	70-100 f	24.9	4/ 3.0	22/ 83[3]	489	136	12.2	3.4	14.4	Cedar Core
	Upper Cedar	Mixed	Comp.	Unk		79	2003			128	70-100 f	unk	unk	18/ 54						Cedar Sat
	Taylor	Native	Wild	Depressed	2	12	98-2003			7.5		1.2	0	54/ 5.5						Cedar Sat
	Peterson	Native	Wild	Depressed	2	1	98-2003			6.4	8 ft	0.2	0	75/ 3.4						Cedar Epi
	Rock	Native	Wild	Depressed	2	3	1960-2003			14.8	17-35 ft	1.3	0	76/ 4.1						Cedar Epi
	Walsh	Native	Wild	Depressed	2	1	98-2003			6.6	8 ft	0.3	0	35/ 5.6						Cedar Epi
N. Lk. Wash.	Bear[5]	Native	Wild	Unk	2	404	85-99	n/a	n/a	50	10-27 ft	17.1	2/ 7.2	61/ 44	21	72	0.5	1.8	2.3	NLW Core
	Little Bear	Native	Wild	Unk	1	11	71-89, 94, 96	1	1 out of 5	15	12-18 ft	7.6	1/ 0.8	56/ 12						NLW Sat
	North[6]	Native	Wild	Unk	1	25	74, 76, 81, 84, 86-88,01	8	3 out of 5	29	10-24 ft	10.8	1/ 0.5	71/ 22						NLW Sat
	Swamp[7]	Native	Wild	Unk	1	6	75-77, 80-81, 84-88, 90	0	0 out of 5	25	10-24 ft	12.2	1/ 2.0	65/ 14						NLW Sat
	Thornton	Native	Wild	Unk	1	3	99-00	1	2 out of 5	11.6	12-15 ft	1.7	1/ 0.2	33/ 4						NLW Epi
	McAleer	Native	Wild	Unk	1	n/a	n/a	11	2 out of 5	3.6	10 ft	2.6	0	61/ 4						NLW Epi
Issaquah	Issaquah[10]	Non-native	Comp.	Healthy	2	2,796	86-99	n/a	n/a	60	8-30 ft	26	5/ 13.4	23/ 34						Iss Core
	Lewis	Non-native	Comp.	Healthy	1	n/a	n/a	9	4 out of 5	1.9		0.6	0	5/ 0.2						Iss Epi
	Laughing Jacobs	Non-native	Comp.	Healthy	1	n/a	n/a	n/a	n/a	16		0.5	1/ 0.5	68/ 0.5						Iss Epi
Unaffiliated based on SASSI and TRT	Kelsey[8]	Native	Wild	Unk	1	138	99-00	70	11 out of 11	17	5-19 ft	13	3/ 5.9	76/ 17						NLW Sat[9]
	Coal	Native	Wild	Unk	1	n/a	n/a	0	1 out of 5	9	7-9 ft	2.1	0	14/ 2						NLW Epi
	May	Native	Wild	Unk	1	2	82, 98-99	2	2 out of 4	14	9-15 ft	3.2	0	49/ 14						NLW Epi
	Juanita	Native	Wild	Unk	1	1	88	0	0 out of 3	6.6	2 ft	2.2	0	60/ 5						NLW Epi
	Pipers	Unk	Unk	Unk	1	n/a	n/a	n/a	n/a	2.9		0.4	0	12/ 1 est.						Unaffiliated Epi

1 from SASSI
2 Minimum life history trajectories currently represents the number of observed juvenile life history strategies
3 Includes Upper Cedar River Watershed
4 Core/Satellite/Episodic:

Core subareas: Chinook salmon are present on an annual basis in the subarea and the subarea represents the center of (highest) abundance for each population affiliation (for spawning, rearing, and migration areas). It is recognized that geographic size of the subarea and the amount or location of suitable spawning and/or rearing habitat often distributed within the subarea (e.g., among tributaries within spawning areas or along shoreline areas) are critical for long term maintenance of the core breeding group, or deme. Because of persistent levels of abundance, the variation in abundance and distribution of these demes have been best accounted for within the watershed, though data gaps exist.

Satellite subareas: Chinook salmon are present most years (more than half the years of a typical 4-5 year life cycle) and are less abundant than in core areas, though population uncertainty exists that is reflective of the level of effort made to determine abundance and distribution. Records are more incomplete, effort is inconsistent among potential satellite areas and methods of enumeration vary. However, it is recognized that geographic size of the subarea and the amount of suitable spawning and rearing habitat often distributed among tributaries within the spawning subarea are critical for long term maintenance of the satellite and core breeding groups

Episodic use subareas: Chinook salmon are present infrequently, and may not be present or observed during the typical 4-5 year life cycle, indicating that when fish are observed, they are strays from another production area and not necessarily the progeny of natural production from the area in question. Epizodic use areas typically are smaller in geographic size, offer limited spawning and rearing opportunities (relative to core and satellite areas), due not only to limited habitat availability, but also due to habitat degradation that likely has a greater negative influence over the limited area, and the likelihood that natural production will be successful and hence contribute to the maintenance of the local breeding group and the core population as a whole.

5 Bear Creek inlcudes Lower Bear, Upper Bear, Cottage Lake and Evans subareas.
6 North Creek includes Upper North and Lower North Creek subareas.
7 Swamp Creek inlcudes Upper Swamp and Lower Swamp Creek subareas.
8 Kelsey Creek includes Upper Kelsey and Lower Kelsey Creeks as well as Mercer Slough.
9 Proximity to Cedar River suggests Kelsey Creek could be a satellite of the Cedar. Geomorphology suggests Kelsey Creek chinook are closer to North Lake Washington population. Technical committee assigns to NLW tribs.
10 Issaquah Subbasin includes North Fork, East Fork, Lower Issaquah, Middle Issaquah, Upper Issaquah, Fifteenmile, and McDonald subareas.

Table 5. WRIA 8 Chinook salmon use designation by population affiliation based on Table 4 and including migratory areas.

	Chinook salmon use		
Population(s)	High (Core spawning, Migratory)	Moderate (Satellite spawning)	Low (Episodic spawning, Non-contributing)
ALL	Lake Washington, Lake Union/Ship Canal, Locks, Nearshore,		
Cedar	Cedar River Main Urban, Cedar River Main Rural,	Upper Cedar (assumed), Taylor Creek,	Rock Creek, Peterson Creek, Walsh Creek, Cedar River North Urban, Cedar River South Urban,
NLW	Bear Creek (Cottage, Upper, Lower), Sammamish River (Upper, Lower),	Bear Creek Evans, Little Bear Creek, North Creek, Swamp Creek, Kelsey Creek,	McAleer Creek, Juanita Creek, Thornton Creek, May Creek, Coal Creek,
Issaquah	Issaquah Creek (Lower, North, East, Middle, Fifteen Mile, Upper), Lake Sammamish, Sammamish River (Upper, Lower),		McDonald Creek, Lewis Creek, East Lake Sammamish tributaries,

Step 7: Intersection of watershed evaluation and fish use results.

Table 6 depicts the intersection of subbasins within bins representing levels of fish use and watershed condition based on the results of Steps 4 and 6 reported above. In order to include all WRIA 8 subbasins, including slow water habitats, the Locks, Lake Washington, Lake Sammamish, and Lake Union/Ship Canal are included (italicized) in Table 6. Their watershed condition is assumed to be degraded based on the highly altered environment, as is described in the WRIA 8 Limiting Factors Report (Kerwin 2001).

Based on the relative watershed condition and level of fish use, three tiers of subbasins are distinguished (Table 7). They are summarized as follows:

Tier 1 – These subbasins include core spawning and obligatory rearing and migratory areas for Chinook salmon without which the WRIA 8 populations could not complete their life cycle.

These are designated Tier 1 regardless of watershed condition for this reason and are areas supporting all VSP attributes for each population. Given basinwide variability among Tier 1 subbasins and their representative habitats, protection and restoration strategies will vary by watershed condition and by life history requirements. These Tier 1 subbasins all contribute significantly to existing productivity and broad subbasin strategies can be developed for each Tier 1 bin (Table 7). For example, subbasins with high fish use representing the spawning core of a population within areas of higher watershed function should be protected (see Table 8 for example subbasin strategies). For these subbasins, specific watershed or habitat strategies and objectives should be developed considering the population objectives derived from the VSP analysis (Appendix C-1). In order to support the VSP objectives (including higher levels of fish use supporting conservation goals), these subbasins should not move toward a moderate level of watershed function.

Table 6. Intersection of watershed evaluation and relative level of current fish use.

	Watershed Evaluation Rating		
Fish Use	Higher Watershed Function	Moderate Watershed Function	Lower Watershed Function
High (Core/ Migratory)	Cedar Main Rural, Bear Creek Upper, Bear Creek Cottage, Issaquah Middle Issaquah Upper Issaquah Fifteenmile Creek	Cedar River Main Urban, Bear Creek Lower, Issaquah Creek Lower, Issaquah Creek East, Sammamish Valley Upper, Sammamish Valley Lower, Issaquah Creek North Fork	*Lake Washington, Lake Union/Ship Canal, Locks, Lake Sammamish*
Moderate (Satellite)	Bear Creek Evans, Cedar Taylor, Cedar River Upper Watershed	Little Bear Creek, North Creek Upper, North Creek Lower	Swamp Creek Upper, Swamp Creek Lower, Kelsey Creek, Mercer Slough
Low (Episodic/ None)	Rock Creek, Peterson Creek, Walsh Creek	May Creek, Tibbetts Creek, Lake Sammamish-East, Issaquah McDonald Creek	Marine Drainages, Cedar South Urban, Cedar North Urban, McAleer Creek, Juanita Creek, Thornton Creek, Coal Creek, Lake Sammamish-West, Lyons Creek, Forbes Creek, Lake Washington - East and West

Table 7. Shaded cells (darkest to lightest) represent Tier 1, Tier 2 and Tier 3 priority subbasins for EDT treatment selection.

	Watershed Evaluation Rating		
Fish Use	Higher Watershed Function	Moderate Watershed Function	Lower Watershed Function
(Core/ Migratory)	**TIER 1**	**TIER 1**	**TIER 1**
(Satellite)	**TIER 2**	**TIER 2**	**TIER 3**
(Episodic/ None)	**TIER 2**	**TIER 3**	**TIER 3**

Tier 2 – These subbasins are composed of satellite spawning areas (11-138 mean annual adult Chinook salmon) with moderate to higher relative watershed condition and are crucial for maintaining and improving the spatial structure, in particular, of the populations. Tier 2 subbasins also include episodic production areas that contain limited favorable habitat for Chinook salmon but which could be productive for this species in the future given an overall greater population abundance and protection of the higher watershed condition. These subbasins are designated as satellite and episodic production areas because 1) production is naturally limited or 2) production is limited by unfavorable subbasin and habitat conditions (all things being equal for the rest of their life history). Based on this difference among Tier 2 subbasins, improving spatial structure, which is dependent upon spatially distributed abundance, will only be accomplished by protecting existing limited production where higher watershed conditions prevail or by improving the productivity of habitat limiting subbasins. The largest benefit will likely be associated with subbasins with the largest size and moderate to higher watershed condition. However, in WRIA 8, Kelsey Creek maintains a larger than expected Chinook salmon spawner abundance given its lower watershed condition rating. At this time Kelsey Creek is grouped with Tier 2 subbasins. Not withstanding the abundance observed in Kelsey Creek, ideally subbasins with moderate levels of fish use and a moderate watershed condition can be improved such that watershed condition improves and a satellite area becomes part of the core of a population.

Tier 3 – These subbasins have either lower watershed condition and significantly impaired watershed processes and degraded aquatic habitat and/or naturally limit production and abundance of Chinook salmon based on subbasin size, channel width, gradient, or length of suitable habitat area. In some cases, in historically significant production areas (e.g., Swamp Creek), Chinook salmon presently are rarely observed and production of other species appears to be limited as well. In other cases, even given the lower watershed condition, these subbasins likely would not contribute directly to significant Chinook salmon production (e.g. Lyons Creek). Instead, these areas remain important to Chinook salmon indirectly for the protection of water quality including temperature, water quantity, and maintenance of downstream habitats such as alluvial deltas in Lakes Washington and Sammamish and the Puget Sound nearshore. As described for Tier 1 and Tier 2 subbasins, appropriate strategies exist for Tier 3 subbasins to assist with recovery of Chinook salmon.

In a schematic sense, recovery will likely be associated with moving subbasins toward the upper left of Table 6 and Table 7, while limiting the movement of subbasin condition toward the bottom right. Over longer time periods this can be monitored based on changes in the watershed indicators and levels of fish use. Table 8 depicts some examples of broad protection or restoration strategies that would target conditions limiting the function of watershed processes, instream habitat and downstream receiving waterbodies and might be applicable to subbasins within subbasin groups.

Table 8. Example of broad subbasin specific strategies for actions applicable to each of the subbasin groups represented within each cell.

	Watershed Evaluation Rating		
Fish Use	Higher Watershed Function	Moderate Watershed Function	Lower Watershed Function
(Core/ Migratory)	Protection of watershed processes and restoration of key limiting factors	Watershed and Habitat Protection/ Restoration; Enhance key life history limiting factors. Focus	Target focus areas and key life history stages understanding altered processes and biological

		may be on life histories most affected and habitats associated with these life stages	communities may not be treated across a larger area of the subbasin
(Satellite)	Watershed processes protection/restoration and restoration of key limiting factors (which may be out of basin)	Habitat protection and restoration; focus mitigation to enhance major limiting factors	Target focus areas and limiting life history stage requirements
(Episodic/ None)	Watershed processes protection/restoration if contributing to downstream quality; lower priority if naturally limiting; Enhance access if limiting to shift production toward satellite level	Habitat protection and restoration if major limiting factors can be treated; Otherwise assume BMPs will sustain watershed condition to support other water quality and species objectives	NPDES-related or other water quality objectives; Maintain support for life history functions during periods of moderate fish use or as subbasin affects downstream water quality

Limitations and Uncertainties
A key limitation of this analysis is the use of a single salmonid species (Chinook) and the assumption that restoration of watershed processes can and should lead to increased frequency and abundance of Chinook. This assumption is reasonable for most of the Satellite areas that are thought to have historically contributed significantly to population viability such as Swamp and North Creeks, but more tenuous for Satellite and Episodic areas that due to basin size or geomorphology are not likely to support significant or sustainable Chinook use, such as Evans Creek or smaller Lake Washington tributary streams. While the broad strategic recommendations in response to watershed condition would be unlikely to change, the inclusion of additional species may result in different binning of sub-areas. This evaluation could be improved with the addition of a fish use or biological condition metric that includes multiple species, allowing sub-area strategies to be linked to broader ecosystem health objectives rather than the status of an individual species.

Step 7. Estimating land cover change and future risk to watershed condition.

For the watershed evaluation, % TIA and % forested land cover from 2001 were two of the eight watershed indicators used. Based on the same land cover classification scheme, Simmonds et al. (2004) analyzed a 1991 Landsat™ image to compare land cover change from 1991 to 2001 in WRIAs 5,7, and 8 at the subbasin and near-stream (riparian) scales. The WRIA 8 data are summarized by Tier group in Table 9 and reported by individual subbasin for %TIA and % forested land cover in Tables 10-12 (based on Simmonds et al. 2004). 2001 land cover ratings and change are depicted in Figures 6 and 7. Based on the change in percent area (e.g., Table 10, column 5), a rate of change for subbasins for the 10-year period can be quantified. When both the amount of gain in TIA and loss in percent forest cover are combined, an additive difference can be calculated (e.g., Table 10, column 8) representing the within area directional and magnitude change in these landscape indicators (Figure 8).

From 1991 to 2001, percent TIA increased in all (45 out of 47 subbasins) but two subbasins (Upper Cedar River and Walsh Lake), and the subbasin average increase in TIA was 7% of land area (Table 9). Forested land cover increased or remained the same in area in 4 out of 47 subbasins (8.5%), declining in 91% of all subbasins. Among all subbasins the additive difference of land cover conversion representing forest loss and gain in TIA averaged 13% of land area (Table 9).

The change in TIA and forested land cover were also estimated within the near stream riparian area (within approximately 90 m either side of type 1-3 fish bearing streams, Table 12). Within this near stream riparian area, the additive difference of land cover conversion representing forest loss and gain in TIA was 8% (Table 9). Riparian forested land cover increased or remained the same in area in 14 out of 44 subbasins (32%). TIA in the riparian area decreased in 6 out of 44 subbasins. However the subbasin average was a gain of 5% TIA in the riparian area.

Table 9. WRIA 8 average change in forest, TIA, and combined additive change by subbasin Tiers and watershed wide. Subbasin area is inclusive of riparian area.

	Forest change, %		TIA change, %		Additive change, %	
Tier	Subbasin	Riparian	Subbasin	Riparian	Subbasin	Riparian
1	-5	-2	5	5	10	7
2	-6	-3	6	4	12	7
3	-6	-4	9	5	15	9
All	-5	-3	7	5	13	8

Additive change is gain in % TIA minus % forest loss

Table 10. 1991, 2001, and 2011 (projected based on 1991-2001 rate of change) subbasin %TIA by area including rate of change (% change over 10 years), additive change and watershed evaluation condition rating.

Subbasin	Tier	1991 TIA (%)	2001 TIA (%)	% rate of change	2011 TIA (%)*	DIFF TIA (%)	DIFF Total Forest (%)	Additive change	1991 TIA rating	2001 TIA rating
North Fork Issaquah	1	7.7	22.1	188	36	14	-13	27	1	3
Lower Sammamish Valley	1	16.7	26.1	57	36	9	-3	12	3	3
Upper Sammamish	1	23.4	32.9	40	42	9	-4	13	3	5
Lower Bear	1	12.2	18.9	56	26	7	-5	12	3	3
Cedar Main Urban	1	15.3	21.6	41	28	6	-6	12	3	3
Cedar Main Rural	1	3.6	9.5	163	15	6	-9	15	1	1
Lower Issaquah	1	5.0	8.6	73	12	4	-1	5	1	1
Cottage Lake	1	7.2	9.9	38	13	3	-8	11	1	1
East Fork Issaquah	1	4.1	6.3	56	9	2	-2	4	1	1
Middle Issaquah	1	0.9	2.3	150	4	1	-6	7	1	1
Fifteenmile	1	0.5	1.4	200	2	1	-8	9	1	1
Upper Bear	1	3.6	4.5	25	5	1	-7	8	1	1
Upper Issaquah	1	0.5	1.4	200	2	1	-4	5	1	1
Upper Cedar	1	0.0	0.0	0	0	0	6	-6	1	1
Mercer Slough	2	23.0	36.9	61	51	14	-11	25	3	5
Upper North	2	24.3	37.4	54	50	13	-9	22	3	5
Lower North	2	15.8	27.9	77	40	12	-8	20	3	3
South Kelsey	2	37.8	47.3	25	57	9	-7	16	5	5
Little Bear	2	8.1	15.8	94	23	8	-9	17	1	3
Evans	2	6.8	13.5	100	20	7	-9	16	1	3
Peterson	2	1.4	5.0	267	9	4	-3	7	1	1
Rock	2	1.8	5.0	175	8	3	-1	4	1	1
Kelsey	2	34.2	37.3	9	40	3	-6	9	5	5
Cedar North Rural	2	2.7	4.1	50	5	1	-7	8	1	1
McDonald	2	3.2	4.5	43	6	1	-2	3	1	1
Walsh	2	0.5	0.5	0	0	0	1	-1	1	1
Nearshore	3	26.1	43.2	65	60	17	-10	27	3	5
Upper Swamp	3	18.9	35.6	88	52	17	-7	24	3	5
Cedar North Urban	3	17.6	32.0	82	46	14	-13	27	3	5
Lower Swamp	3	27.9	39.2	40	50	11	-7	18	3	5
West Lake Washington	3	45.5	56.7	25	68	11	0	11	5	5
Cedar South Urban	3	23.9	34.7	45	45	11	-3	14	3	5
East Lake Sammamish	3	6.3	16.2	157	26	10	-13	23	1	3
McAleer	3	39.2	49.1	25	59	10	-6	16	5	5
Mercer Island	3	22.7	32.3	42	42	10	-9	19	3	5
Coal	3	12.2	21.6	78	31	9	-8	17	3	3
East Lake Washington	3	28.8	38.3	33	48	9	-6	15	3	5
West Lake Sammamish	3	24.3	33.8	39	43	9	-7	16	3	5
Forbes	3	28.8	37.4	30	46	9	-6	15	3	5
Green Lake	3	51.8	59.0	14	66	7	-2	9	5	5
Juanita	3	39.6	46.8	18	54	7	-5	12	5	5
May	3	8.6	15.8	84	23	7	-6	13	1	3
Lake Union	3	61.2	68.4	12	76	7	-1	8	5	5
Lyons	3	30.2	36.9	22	44	7	-6	13	5	5
Thornton	3	50.4	56.3	12	62	6	-3	9	5	5
North Lake Washington	3	34.2	39.6	16	45	5	1	4	5	5
Tibbetts	3	7.7	11.3	47	15	4	-1	5	1	3

Table 11. 1991, 2001, and 2011 (projected based on 1991-2001 rate of change) Subbasin % Forest by area including rate of change (% change over 10 years), additive change and watershed evaluation condition rating.

Subbasin	Tier	1991 Forest (%)	2001 Forest (%)	% rate of change	2011	DIFF Total Forest (%)	DIFF TIA (%)	Additive change	1991 Forest rating	2001 Forest rating
North Fork Issaquah	1	44	31	-30	22	-13	14	27	5	3
Cedar Main Rural	1	55	46	-16	38	-9	6	15	5	5
Fifteenmile	1	69	61	-12	54	-8	1	9	5	5
Cottage Lake	1	36	28	-22	22	-8	3	11	3	3
Upper Bear	1	50	43	-14	37	-7	1	8	5	5
Middle Issaquah	1	48	42	-13	37	-6	1	7	5	5
Cedar Main Urban	1	27	21	-22	16	-6	6	12	3	3
Lower Bear	1	24	19	-21	15	-5	7	12	3	1
Upper Issaquah	1	53	49	-8	45	-4	1	5	5	5
Upper Sammamish	1	12	8	-33	5	-4	9	13	1	1
Lower Sammamish	1	20	17	-15	14	-3	9	12	1	1
East Fork Issaquah	1	66	64	-3	62	-2	2	4	5	5
Lower Issaquah	1	53	52	-2	51	-1	4	5	5	5
Upper Cedar	1	72	78	9	85	6	0	-6	5	5
Mercer Slough	2	18	7	-61	3	-11	14	25	1	1
Evans	2	38	29	-24	22	-9	7	16	3	3
Little Bear	2	35	26	-26	19	-9	8	17	3	3
Upper North	2	19	10	-47	5	-9	13	22	1	1
Lower North	2	23	15	-35	10	-8	12	20	3	1
Cedar North Rural	2	38	31	-18	25	-7	1	8	3	3
South Kelsey	2	14	7	-50	4	-7	9	16	1	1
Kelsey	2	19	13	-31	9	-6	3	9	1	1
Peterson	2	42	39	-7	36	-3	4	7	5	3
McDonald	2	38	36	-5	34	-2	1	3	3	3
Rock	2	46	45	-2	44	-1	3	4	5	5
Walsh	2	75	76	1	77	1	0	-1	5	5
East Lake Sammamish	3	39	26	-33	17	-13	10	23	3	3
Cedar North Urban	3	24	11	-54	5	-13	14	27	3	1
Nearshore	3	21	11	-47	6	-10	17	27	3	1
Mercer Island	3	18	9	-50	5	-9	10	19	1	1
Coal	3	29	21	-28	15	-8	9	17	3	3
West Lake Sammamish	3	22	15	-32	10	-7	9	16	3	1
Lower Swamp	3	15	8	-47	4	-7	11	18	1	1
Upper Swamp	3	17	10	-41	6	-7	17	24	1	1
Lyons	3	18	12	-33	8	-6	7	13	1	1
May	3	34	28	-18	23	-6	7	13	3	3
Forbes	3	16	10	-38	6	-6	9	15	1	1
East Lake Washington	3	18	12	-33	8	-6	9	15	1	1
McAleer	3	12	6	-50	3	-6	10	16	1	1
Juanita	3	11	6	-45	3	-5	7	12	1	1
Thornton	3	6	3	-50	2	-3	6	9	1	1
Cedar South Urban	3	19	16	-16	13	-3	11	14	1	1
Green Lake	3	3	1	-67	1	-2	7	9	1	1
Tibbetts	3	43	42	-2	41	-1	4	5	5	5
Lake Union	3	2	1	-50	1	-1	7	8	1	1
West Lake Washington	3	4	4	0	4	0	11	11	1	1
North Lake Washington	3	5	6	20	7	1	5	4	1	1

Table 12. 1991, 2001 and 2011 (projected based on 1991-2001 rate of change) near-stream (within 275 feet) % forest and %TIA land cover composition by area including rate of change (% change over 10 years), additive change and riparian condition rating from the watershed evaluation matrix (Table 3).

						Riparian rating		Riparian TIA, (%)			Forest and TIA
Subbasin	1991	2001	Forest change	% rate of change	2011 Rip. %	1991	2001	1991	2001	TIA change	Additive change
Lower Samm Valley	15	11	-4	-25	8.40	1	1	17	34	17	21
Cedar Main Urban	33	24	-9	-27	17.45	3	3	12	16	5	14
Upper Sammamish	9	6	-3	-33	4.00	1	1	11	21	10	13
Lower Bear	23	20	-3	-13	17.39	3	3	6	14	8	11
North Fork Issaquah	43	40	-3	-6	37.96	5	5	7	13	6	9
Cedar Main Rural	59	54	-5	-8	49.42	5	5	2	4	2	7
East Fork Issaquah	42	42	0	0	42.00	5	5	13	20	7	7
Cottage Lake	31	27	-4	-13	23.52	3	3	5	6	2	6
Lake Sammamish	22	15	-7	-32	10.23	3	1	4	9	6	13
Fifteenmile	67	64	-3	-4	61.13	5	5	1	3	2	5
Middle Issaquah	42	39	-3	-7	36.21	5	3	1	1	0	3
Lower Issaquah	39	41	2	5	43.10	3	5	5	9	4	2
Upper Bear	49	49	0	0	49.00	5	5	2	4	2	2
Upper Issaquah	52	52	0	0	52.00	5	5	0	1	1	1
Upper Cedar	90	93	3	3	96.10	5	5	0	0	0	-3
Lower North	22	16	-6	-27	11.64	3	1	12	26	14	20
Upper North	33	24	-9	-27	17.45	3	3	10	18	7	16
Cedar North Rural	31	24	-7	-23	18.58	3	3	5	8	3	10
Little Bear	30	24	-6	-20	19.20	3	3	13	16	3	9
Evans	35	31	-4	-11	27.46	3	3	4	8	5	9
Kelsey	14	9	-5	-36	5.79	1	1	26	27	2	7
Peterson	39	34	-5	-12	30.24	3	3	2	4	2	6
South Kelsey	20	17	-3	-15	14.45	3	1	25	28	3	6
McDonald	49	50	1	2	51.02	5	5	2	3	0	-1
Walsh	79	80	1	1	80.60	5	5	0	0	0	-1
Rock	52	58	6	12	64.69	5	5	1	2	1	-5
Nearshore	47	36	-11	-23	27.84	5	3	9	22	13	24
Upper Swamp	33	21	-12	-36	13.36	3	3	9	19	10	22
May	32	24	-8	-25	18.00	3	3	5	13	8	16
Forbes	24	20	-4	-17	16.67	3	3	12	21	9	13
West Lake Sammamish	34	29	-5	-15	24.74	3	3	13	19	6	11
McAleer	24	17	-7	-29	12.04	3	1	15	18	4	11
East Lake Sammamish	36	31	-5	-14	26.69	3	3	5	10	5	10
Lower Swamp	21	17	-4	-19	13.76	3	1	15	22	6	10
East Lake Washington	24	16	-8	-33	10.67	3	1	28	30	2	10
Lyons	24	17	-7	-29	12.04	3	1	20	23	3	10
Cedar South Urban	26	26	0	0	26.00	3	3	11	20	9	9
Cedar North Urban	34	31	-3	-9	28.26	3	3	18	23	5	8
Thornton	7	7	0	0	7.00	1	1	36	42	6	6
Coal	33	35	2	6	37.12	3	3	11	15	5	3
Mercer Slough	17	17	0	0	17.00	1	1	35	35	0	0
Juanita	12	13	1	8	14.08	1	1	36	36	1	0
Tibbetts	42	46	4	10	50.38	5	5	4	6	2	-2
North Lake Washington	4	2	-2	-49	1.04	1	1	40	36	-4	-2

Assuming land cover change will continue to occur, it is reasonable to expect that the watershed indicators will change rating values as new impervious surfaces are added or remaining forested land cover is lost. Tracking this cumulative change and identifying future areas at risk of additional growth is potentially instructive for a conservation strategy in light of how land cover classification was used to determine input ratings for the watershed evaluation. Based on the rate of land cover change, and TIA and forest rating criteria, subbasin ratings in 1991, 2001 and 2011 (or some future date) can be estimated based on potential future growth. It is expected that in some of the most developed subbasins (e.g., Thornton Creek) the future rating value will not change. This is also true in subbasins without development (e.g., Upper Cedar River). However in those subbasins where significant change has occurred, the TIA or forest cover rating may shift from one threshold or tier of watershed condition into another, thereby crossing significant demarcations associated with the watershed and habitat degradation. An estimate of future risk can be part of the conservation strategy development for action prioritization based on geography and treatment for the populations in question.

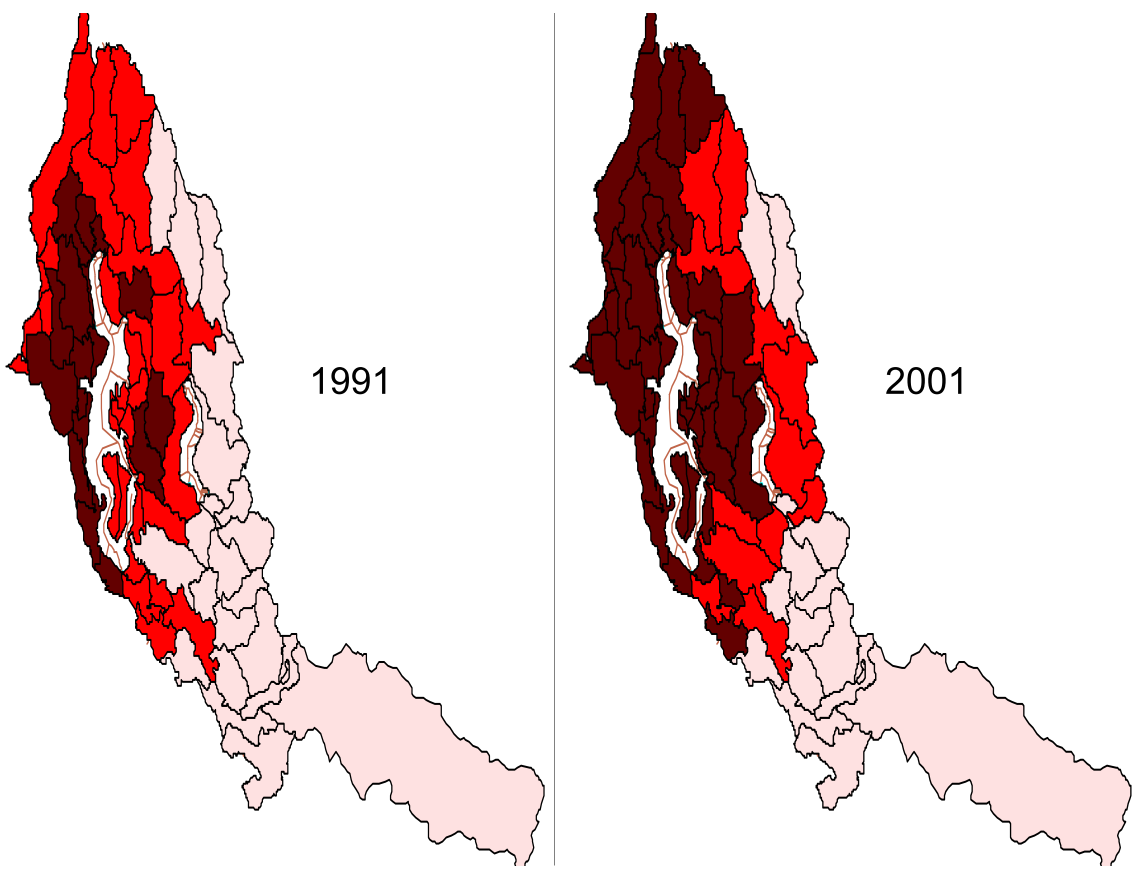

Figure 6. 1991 and 2001 %TIA land cover rating by subbasin. From lightest to darkest shading, %TIA rating criteria categories are; <10 %, 10-30%, and >30% (see Table 2).

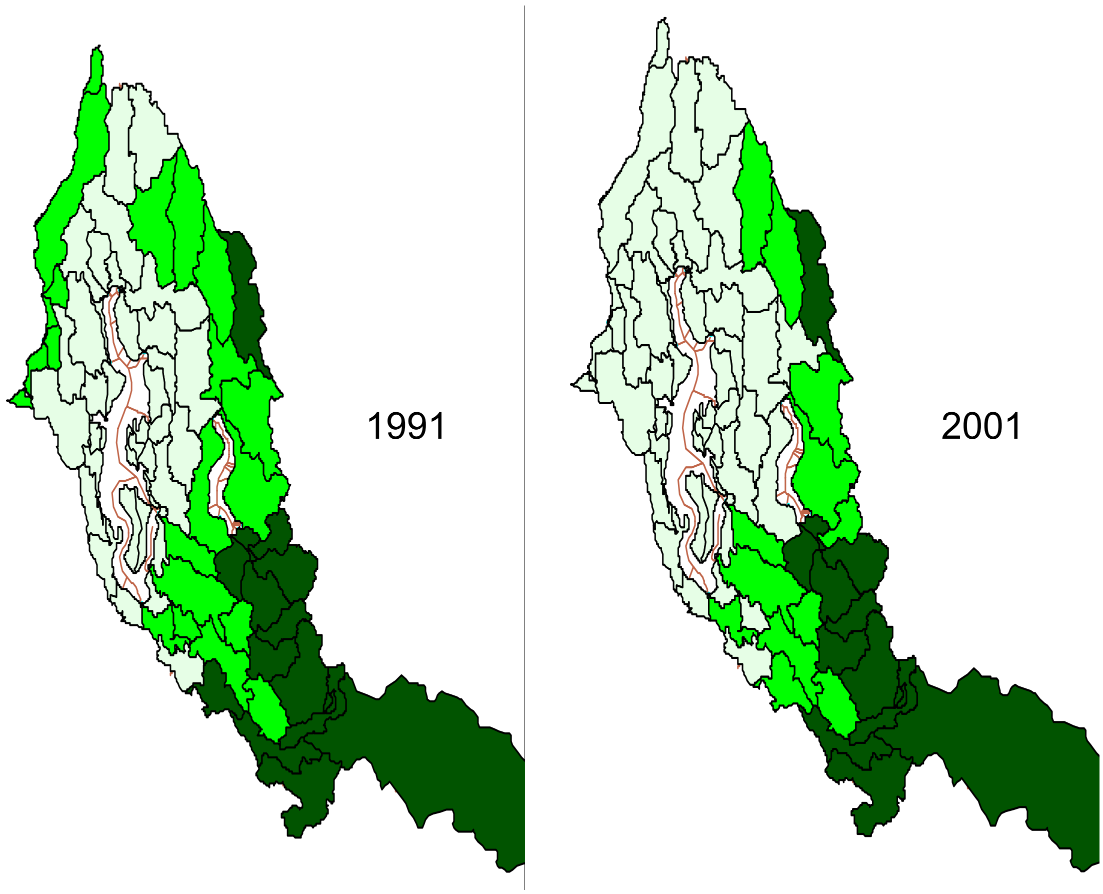

Figure 7. 1991 and 2001 % forested land cover rating by subbasin. From lightest to darkest shading, % forest rating criteria categories are; <20 %, 20-40%, and >40% (see Table 2).

Based on the change in subbasin TIA and forested land cover, as well as the estimated change in riparian forested land cover among Tier 1, 2 and 3 subbasins (Tables 9, 10 and 11), the most "at-risk" subbasins are listed below by Tier and by broad protection or restoration objectives. For example, Upper Bear, Cedar Main Rural and Cottage Lake have exhibited a high rate of forest loss in combination with increases in TIA within these core areas of Chinook salmon production. Based on the populations affected, level of Chinook salmon use and potential for success of a preservation and restoration strategy within these core areas, these subbasins are identified as being at high risk of future change and various protection and restoration emphases are noted:

Tier 1 -

- Upper Bear - Forest cover and TIA protection
- Cottage Lake - Forest cover and TIA protection
- Lower Bear - Riparian protection and restoration
- Cedar Main Urban - Riparian restoration
- Cedar Main Rural - Forest cover and TIA protection
- Middle Issaquah - No VSP objectives
- North Fork Issaquah - No VSP objectives
- East Fork Issaquah - No VSP objectives
- Lower Issaquah - No VSP objectives

Within this select list of subbasins, additional prioritization for actions may be appropriate (especially in light of the lack of VSP objectives for Issaquah Creek at this time).

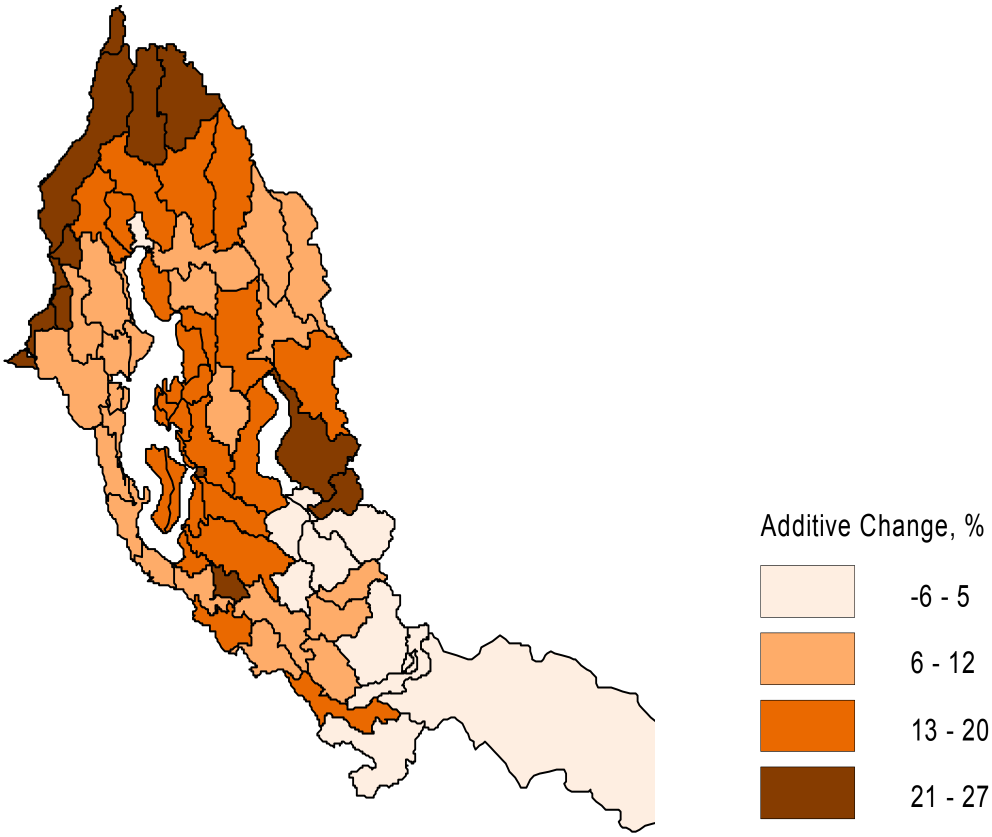

Figure 8. WRIA 8 subbasin additive land cover change by area. Additive land cover represents the gain in %TIA minus the loss in %forest cover.

Among Tier 2 subbasins, the most at-risk subbasins, based on the watershed condition, level of fish use within these satellite areas and existing rates of change are:

- Peterson Creek - Forest cover and TIA protection
- Rock Creek - Forest cover and TIA protection
- Evans Creek - Forest cover and TIA protection; Riparian and floodplain protection and restoration
- Little Bear Creek - Forest cover and TIA protection; Riparian and floodplain protection and restoration
- Cedar North Rural - Forest cover and TIA protection; Riparian protection and restoration
- Upper North Creek - Riparian and floodplain protection and restoration
- Lower North Creek - Riparian and floodplain protection and restoration

Among these subbasins, only Evans, Little Bear and Lower North have shifted from one rating level to the next highest for TIA. Rock and Peterson exhibit the highest rate of increase in TIA (based on 1991 to 2001 land cover conversion). These are areas where land use planning, management through land use regulations and application of non-structural and structural BMPs could be successful. Lower North, Evans and Little Bear are most at-risk but also likely retain the greatest restoration potential among Tier 2 subbasins given the level of fish use present and spawner capacity (i.e., Sanderson et al. 2003). At the same time, if fish use continues to decline to a level of episodic use, then these subbasins could change from Tier 2 status to Tier 3.

Among Tier 3 subbasins, 12 of 21 subbasins shifted from one TIA category to a higher TIA category from 1991 to 2001 (Figure 6). In general, the rate of land cover change has been less than the rate of change in Tier 1 and 2 subbasins (see Table 9), in part because these subbasins were already developed or developing within urban growth areas. At this time there are no data specific to UGA boundaries to evaluate the rate and extent of change within and outside of urban growth areas. Among Tier 3 subbasins, these are most at-risk of being removed from the conservation geography of Chinook salmon in WRIA 8 due to episodic abundance and lower watershed condition coupled with preceding and potential future land cover changes:

- May Creek
- Coal Creek
- Upper Swamp Creek
- Lower Swamp Creek
- McAleer Creek
- East Lake Sammamish

Estimates of future land cover change can be made to further refine the identification of at-risk sub-basins. Table 13 shows the projected 2011 watershed ratings for TIA, forest cover, and riparian forest cover based on the assumption that 1991-2001 land cover change rates continue at the same rate until 2011. This simplistic assumption about future conditions results in several subbasins shifting downward in overall watershed condition, as a result of increased TIA and decreased riparian or subbasin forest cover. In addition, several more subbasins were at risk of being recategorized in a lower tier. As shown in Table 13, changes in individual watershed indicator ratings are projected for the following subbasins in 2011:

<u>Increased TIA Impact Factor:</u>

- Cedar Main Rural (Tier 1)
- Bear Cottage (Tier 1)
- Issaquah Lower (Tier 1)
- North Lower (Tier 2)
- Sammamish Valley Lower (Tier 3)

<u>Decreased Forest Cover Mitigative Factor</u>

- Cedar Main Rural (Tier 1)
- Issaquah Lower (Tier 1)
- Issaquah North (Tier 1) – some of the past change is due to construction of I-90 ramps
- North Lower (Tier 2)
- Sammamish Valley Lower (Tier 3)

<u>Decreased Riparian Forest Cover Mitigative Factor:</u>

- Bear Lower (Tier 1)
- Issaquah North (Tier 1) – some of the past change is due to construction of I-90 ramps
- Cedar Main Urban (Tier 1)
- Cedar North Rural (Tier 2)

- North Upper (Tier 2)
- Little Bear (Tier 2)
- May (Tier 3)
- Forbes (Tier 3)
- Swamp Upper (Tier 3)

As a result of these projected changes in watershed impact and mitigative factors due to land cover changes, subbasins that would be reclassified from a relatively high level of watershed condition to a moderate condition are:

- Cedar North Rural (Tier 2)

Subbasins that would be reclassified from a relatively moderate level of watershed condition to a low condition due to projected changes in future land cover are:

- Little Bear Creek (Tier 2)

Based on this analysis, subbasins projected to be at risk of being reclassified from one level of watershed condition to another are:

- Cedar Main Urban (Tier 1, Moderate to Low)
- North Creek (Tier 2, Moderate to Low)

Finally, subbasins with the largest change in overall watershed score are:
- Cedar Main Rural (Tier 1, -4)
- Issaquah North (Tier 1, -4) - some of the past change is due to construction of I-90 ramps
- Cedar Main Urban (Tier 1, -4)
- Little Bear (Tier 2, -4)
- Coal Creek (Tier 3, -4)

While the projected land cover change for 2011 is speculative given the simplistic assumption that future land cover change will occur at the same rate as 1991-2001, it does serve to highlight the ongoing risks to habitat condition and biotic integrity due to land cover change (see Step 4 above) if current trends continue. These changes would be expected to affect the conservation geography for Chinook salmon in WRIA 8. For example, a critical VSP objective for the North Lake Washington Chinook population is to expand the spatial distribution of the population so that it is not focused solely on the Bear/Cottage Lake Creek system. This objective will be more difficult to achieve if overall watershed condition in North and Little Bear Creeks declines from moderate to low condition. Similarly, a key VSP objective for the Cedar Chinook population is to increase productivity in the mainstem Cedar River below Landsburg Dam. Declining watershed condition in the Cedar Main Urban subbasin combined with increased TIA and decreased forest cover in the Cedar Main Rural subbasin could put these objectives at risk if current land cover trends continue.

Table 13. 2011 Projected Watershed Rating based on 1991-2001 Rate of Change in Riparian Forest %, Basin Forest Cover %, and TIA %.

Indicator	Riparian rating			Forest Cover %			TIA %			2001 vs 2011 Watershed Condtion			
Subbasin	1991	2001	2011	1991	2001	2011	1991	2001	2011	2001 Score	2001 Rating	2011 Score	2011 Rating
Cedar Lower Rock	5	5	5	5	5	5	1	1	1	14	High	14	High
Cedar Peterson	3	3	3	5	3	3	1	1	1	10	High	10	High
Cedar Main Rural	5	5	5	5	5	3	1	1	3	12	High	8	High
Bear Cottage Lake	3	3	3	3	3	3	1	1	3	10	High	8	High
Bear Upper	5	5	5	5	5	3	1	1	1	10	High	8	High
Bear Evans	3	3	3	3	3	3	1	3	3	6	High/Mod	6	High/Mod
Cedar Upper	5	5	5	5	5	5	1	1	1	6	High	6	High
Cedar Walsh	5	5	5	5	5	5	1	1	1	6	High	6	High
Issaquah Fifteenmile	5	5	5	5	5	5	1	1	1	4	Mod	4	Mod
Issaquah McDonald	5	5	5	3	3	3	1	1	1	4	High	4	High
Issaquah Upper	5	5	5	5	5	5	1	1	1	4	High	4	High
Cedar North Rural	3	3	1	3	3	3	1	1	1	4	High	2	Mod
Issaquah Lower	3	5	5	5	5	5	1	1	3	4	Mod	2	Mod
Lake Samm. East	3	3	3	3	3	1	1	3	3	4	Mod	2	Mod
Issaquah East	5	5	5	5	5	5	1	1	1	2	Mod	2	Mod
Samm. Valley Upper	1	1	1	1	1	1	3	5	5	2	Mod	2	Mod
Issaquah North	5	5	3	5	3	3	1	3	5	4	High	0	Mod
Bear Lower	3	3	1	3	1	1	3	3	3	2	Mod	0	Mod
Issaquah Middle	5	3	3	5	5	3	1	1	1	2	Mod	0	Mod
May	3	3	1	3	3	3	1	3	3	2	Mod	0	Mod
Samm. Valley Lower	1	1	1	1	1	1	3	3	5	2	Mod	0	Mod
Cedar Main Urban	3	3	1	3	3	1	3	3	3	2	Mod	-2	Mod
North Lower	3	1	1	3	1	1	3	3	5	0	Mod	-2	Mod
North Upper	3	3	1	1	1	1	3	5	5	0	Mod	-2	Mod
Tibbetts	5	5	5	5	5	5	1	3	3	-2	Mod	-2	Mod
Kelsey Lower	3	1	1	1	1	1	5	5	5	-4	Low	-4	Low
Little Bear	3	3	1	3	3	1	1	3	3	-2	Mod	-6	Low
Forbes	3	3	1	1	1	1	3	5	5	-4	Low	-6	Low
Swamp Upper	3	3	1	1	1	1	3	5	5	-4	Low	-6	Low
Cedar South Urban	3	3	3	1	1	1	3	5	5	-6	Low	-6	Low
Swamp Lower	3	1	1	1	1	1	3	5	5	-6	Low	-6	Low
Cedar North Urban	3	3	3	3	1	1	3	5	5	-8	Low	-8	High
Kelsey Upper	1	1	1	1	1	1	5	5	5	-8	Low	-8	Low
McAleer	3	1	1	1	1	1	5	5	5	-8	Low	-8	Low
Coal	3	3	3	3	3	1	3	3	5	-6	Low	-10	Low
Juanita	1	1	1	1	1	1	5	5	5	-10	Low	-10	Low
Lake Wa. East	3	1	1	1	1	1	3	5	5	-10	Low	-10	Low
Marine Drainages	5	3	3	3	1	1	3	5	5	-10	Low	-10	Low
Thornton	1	1	1	1	1	1	5	5	5	-12	Low	-12	Low
Lake Samm. West	3	3	3	3	1	1	3	5	5	-14	Low	-14	Low
Lake Wa. West	3	1	1	1	1	1	5	5	5	-14	Low	-14	Low
Lyon	3	1	1	1	1	1	5	5	5	-14	Low	-14	Low

The results shown here related to watershed indicators, habitat condition and land cover change and the interpretation offered here regarding risk associated with land cover change to the conservation geography in WRIA 8 is supported by others. May et al. (1997) and Booth et al. (in press) have shown that at low levels of watershed development (i.e. <10 % impervious area) the observed high variability in biotic integrity or habitat conditions is governed by a strong response to forest cover reduction. Given the high level of sensitivity to impacts and documented value these areas strong protection is warranted. At the very highest levels of development, the observed variability in biotic integrity is low as are the measures of biotic integrity or habitat conditions presumably because impacts associated with land development, hydrologic alteration, and riparian degradation overwhelm remaining mitigative factors. In these areas successful restoration of natural conditions is unlikely, thus management approaches based on doing no further harm (especially through critical areas regulation and treatment of stormwater quantity and quality) and stewardship activities are beneficial.

Where land development is intermediate, there appears to be high variability in both habitat conditions in aquatic areas (May et al. 1997) and measures of biotic integrity even given usually lower levels of remaining forest cover and alteration of hydrologic regime (Booth et al. in press). In numerous studies, it has been demonstrated that the mitigative value of higher quality or intact riparian and floodplain corridors contributes substantially to the retention and even improvement of biotic integrity and habitat conditions (May et al. 1997; Morley and Karr 2002; Booth et al. in press). For example, this has been documented in Snohomish County in Little Bear Creek (Morley and Karr 2002). As well, Booth et al. (in press) demonstrated that Biotic integrity as measured by B-IBI, was higher in subbasins where riparian areas had less urban land cover. Hence it is in these areas where rehabilitation is likely to succeed, dependent upon the correct identification of factors affecting aquatic areas and treatment of causes as well as effects.

Limitations and Uncertainties

The most significant limitation of this step is the prediction of future rates of land cover change. The assumption that the next 10 years of land cover change will be the same as the last 10 years is highly speculative, but can be informative if applied cautiously to highlight areas that may see significant change in land cover if recent trends continue. Examples where this assumption is most obviously erroneous are those areas that are nearing build-out and therefore are not capable of supporting the same rate of land cover change (e.g. Thornton Creek), and those areas where land use planning and regulations have changed significantly since the 1990s, (ie subbasins where regulations and incentive programs were developed in the 1990s such as the Cedar Main Rural sub-area). Estimates of likely future land cover change will be revised as more refined analytical tools become available. In the near term, this analysis could be strengthened using zoning information from local government Comprehensive Plans along with an analysis of regulatory changes. This information would help to refine future land cover change estimates in areas where land use zoning and regulations may alter recent rates of development. In the longer term, future land cover change predictions could be improved with analyses from the UrbanSim model being used by the Puget Sound Regional Council, which generates future land cover change predictions using multiple factors such as local government zoning, transportation planning, and economic indicators.

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Figure S1. 2001 %TIA.

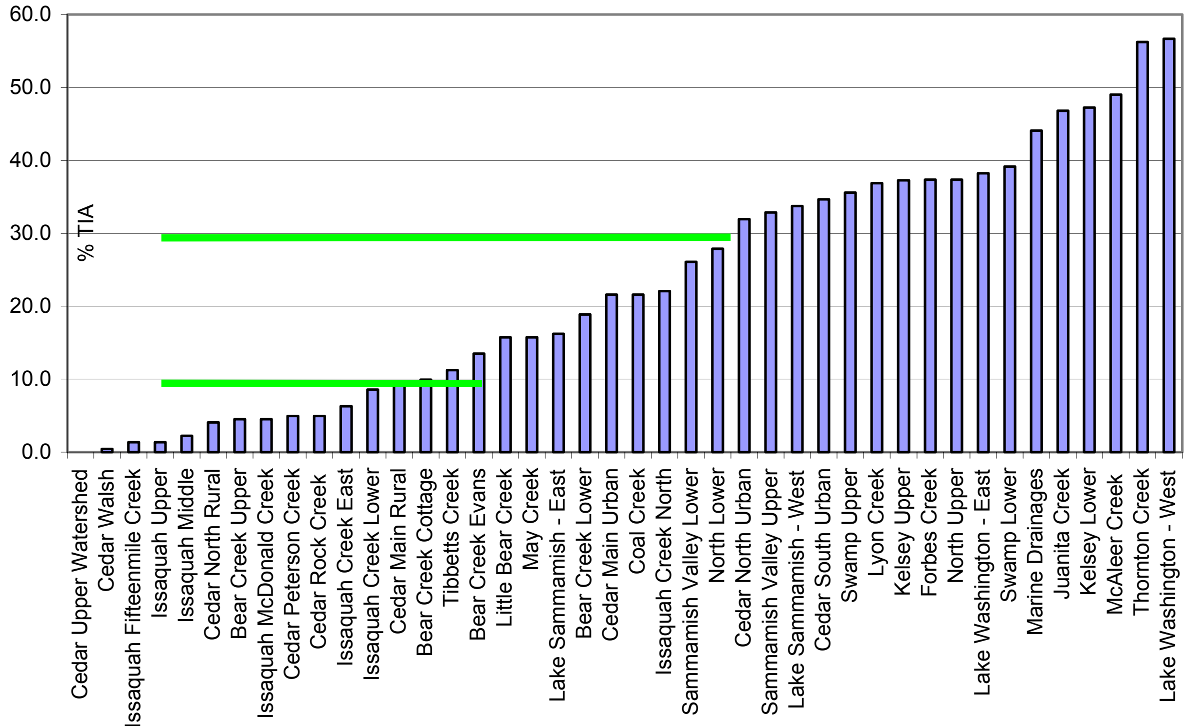


Figure S-2. 1998 Flow Volume Change

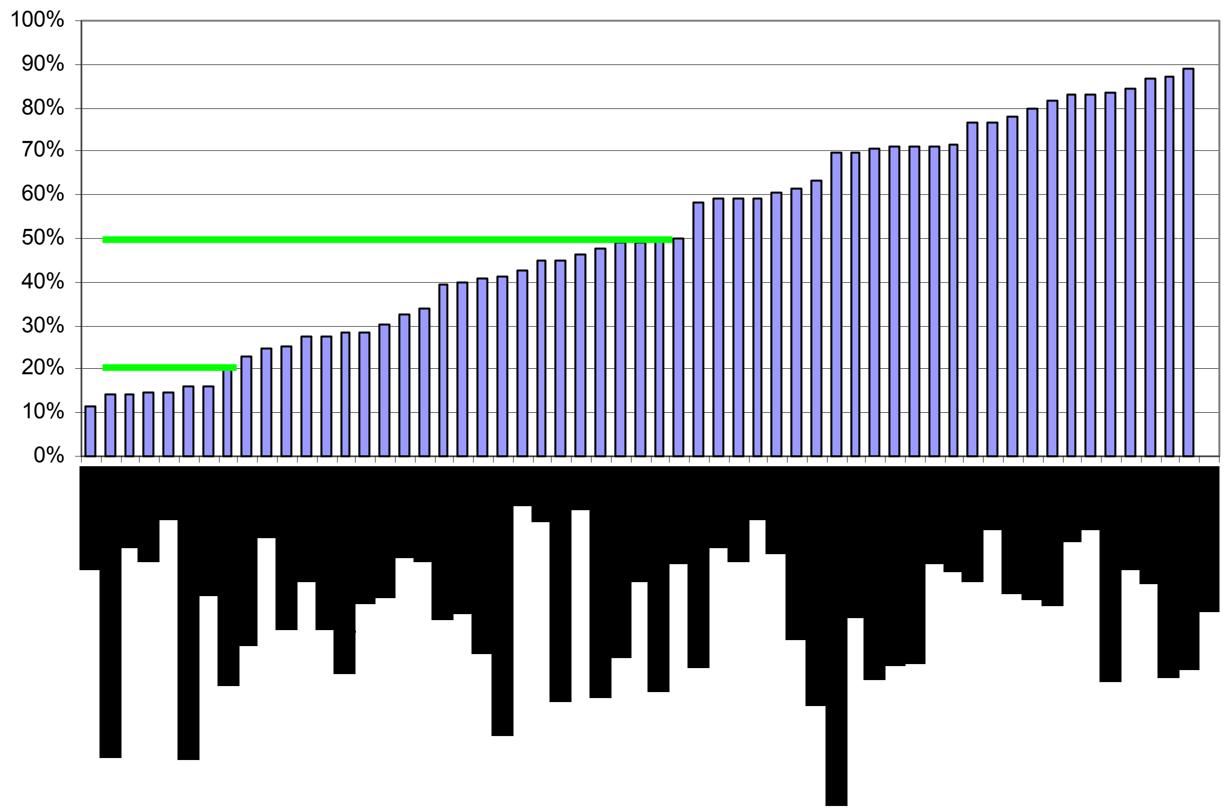


Figure S-3. Gradient >4%.

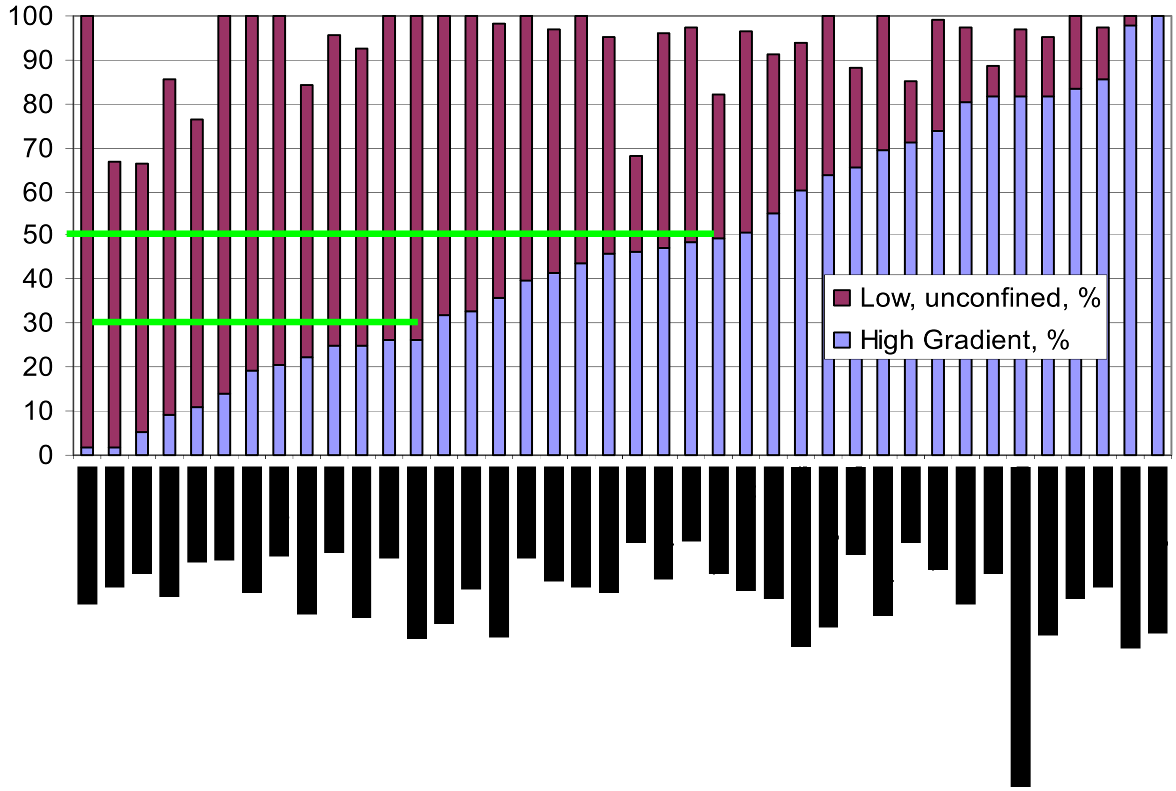


Figure S-4. Road crossing frequency.

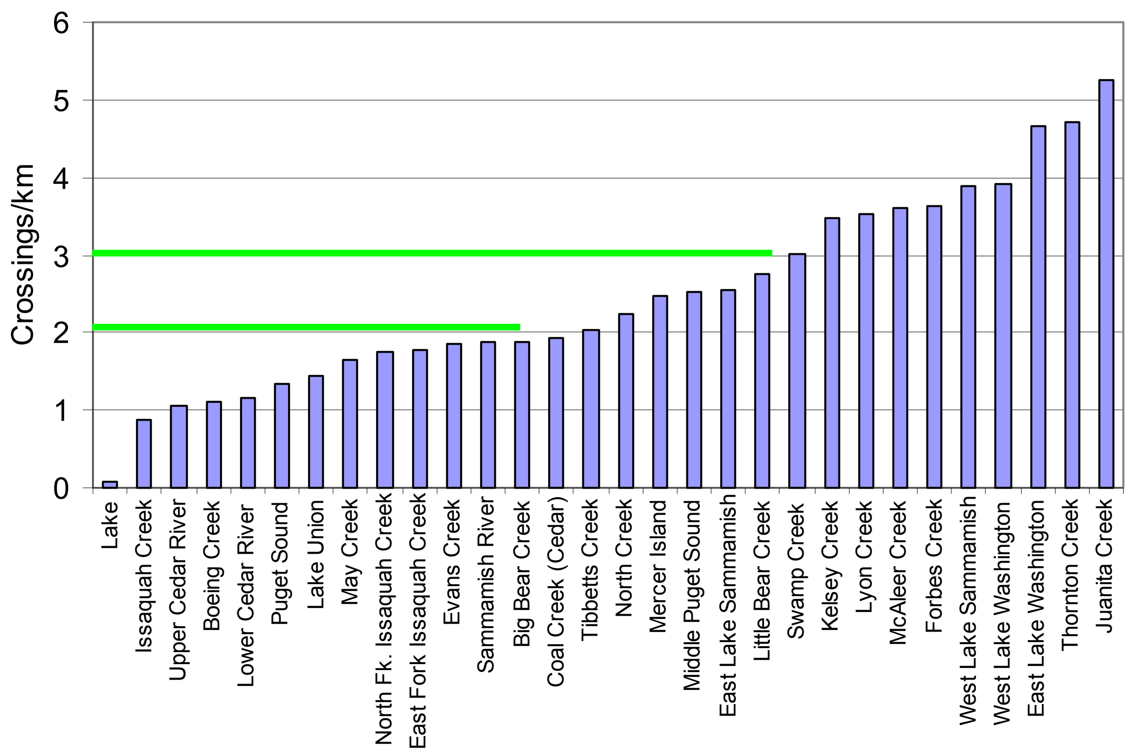


Figure S-5. %Wetland area.

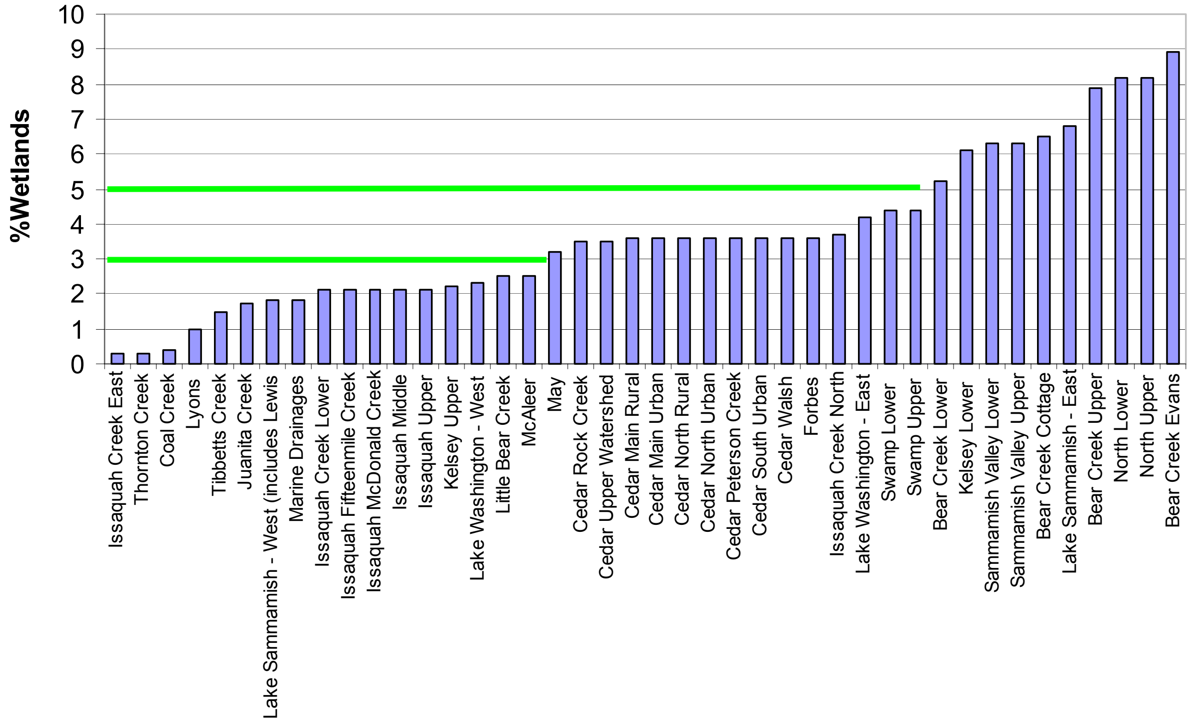


Figure S-6. % Low gradient, unconfined stream reaches.

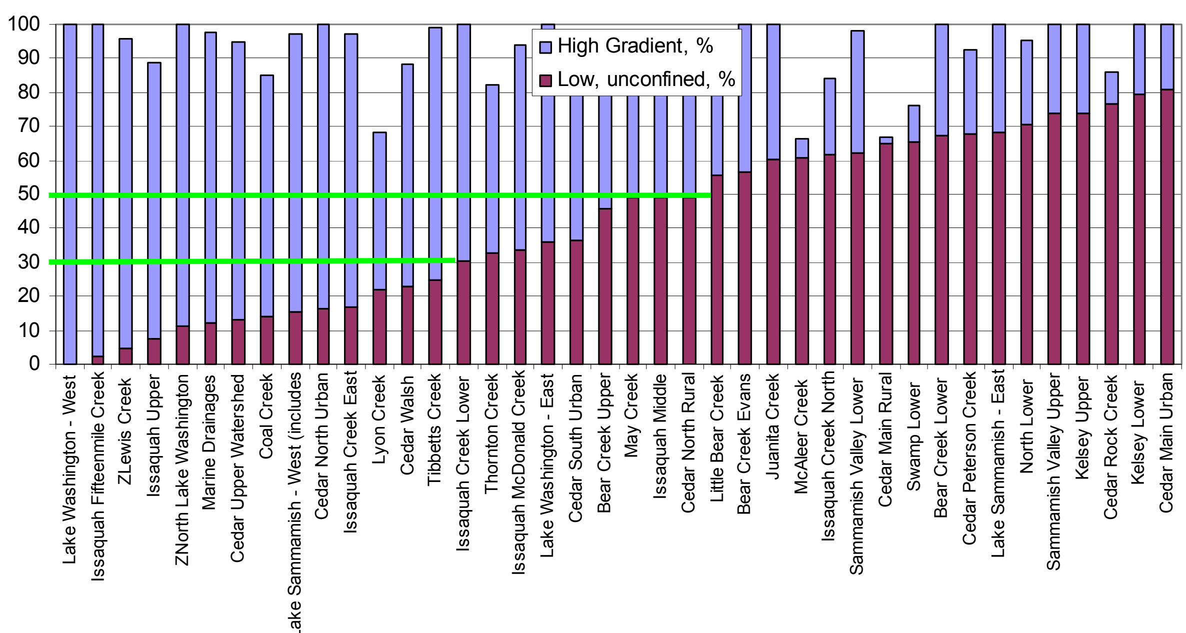


Figure S-7. % Total subbasin forest area.

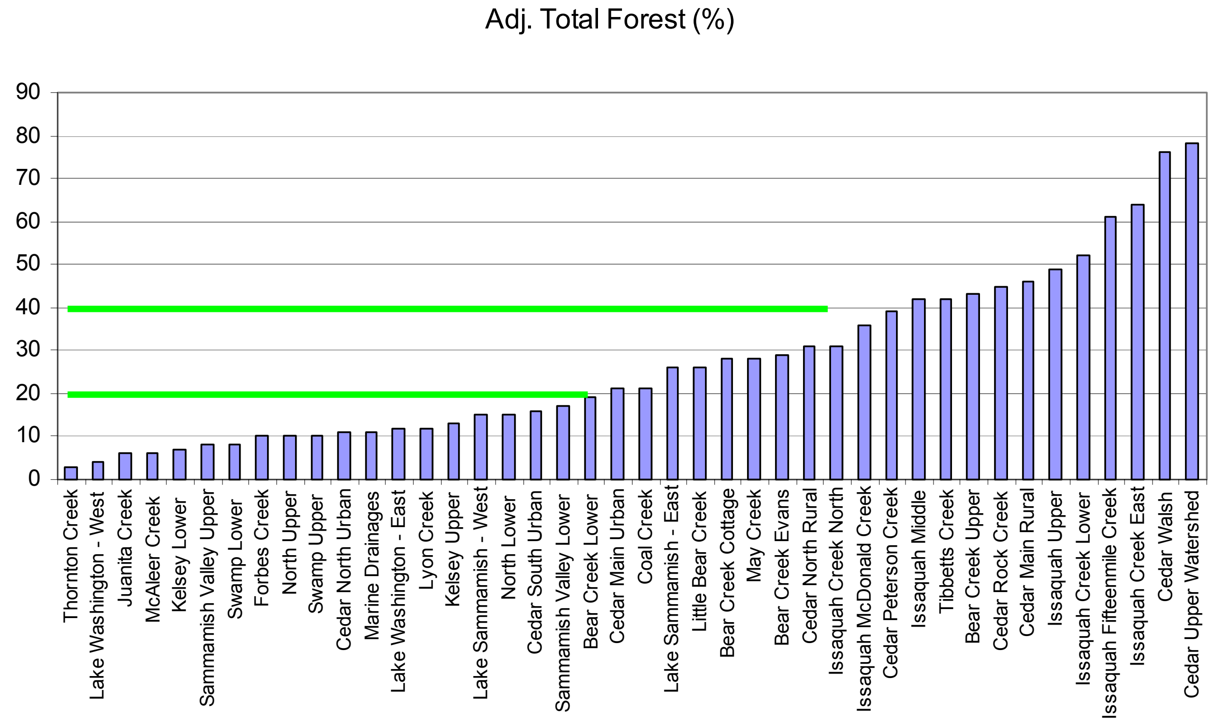
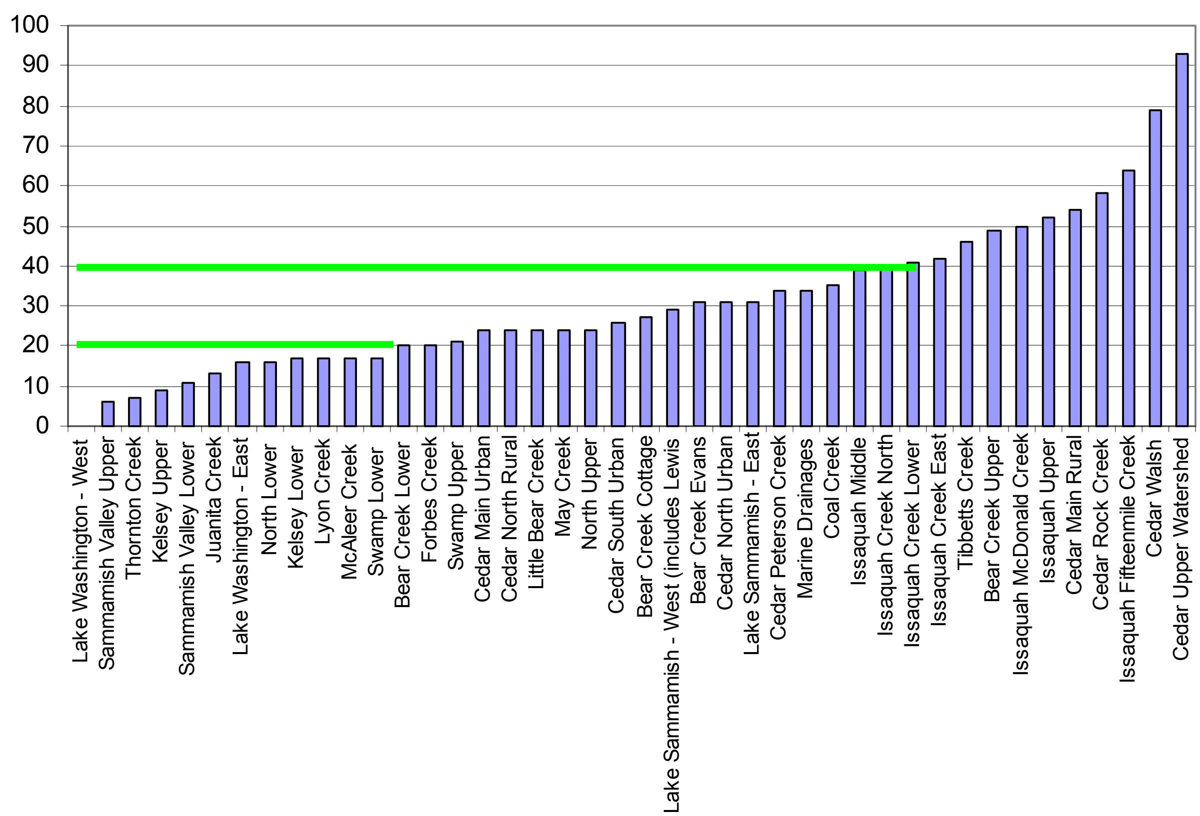


Figure S-8. % Riparian forest area.



Appendix C-3
WRIA 8 Ecosystem Diagnosis and Treatment (EDT) Habitat Modeling

1 Introduction and Purpose

The WRIA 8 Conservation Plan is the product of the multi-jurisdictional, multi-stakeholder watershed planning process for the Greater Lake Washington watershed—Watershed Resource Inventory Area 8 (WRIA 8). The intent of this plan is to protect and enhance habitat conditions that support viable Chinook salmon populations in WRIA 8. The WRIA 8 Technical Committee (W8TC) has developed a technical foundation and documentation to support the development of this plan. One element of this foundation is a strategic assessment of salmon populations and habitat conditions within WRIA 8. As part of this assessment the W8TC determined that an analytical tool was needed to relate salmonid survival to habitat conditions so that habitat conservation actions could be developed and evaluated. The W8TC determined that a modified version of the Ecosystem Diagnosis and Treatment (EDT) model would be a useful habitat assessment model for WRIA 8. The modified WRIA 8 version of EDT described in this appendix was developed by the WRIA 8 Technical Committee in collaboration with Mobrand Biometrics Inc. (MBI).

The EDT habitat assessment model project was initiated in September of 2002. The project had several objectives: (a) customization of the EDT model for the WRIA 8 watershed; (b) gather, organize and input habitat and salmon (Chinook and coho) population data for the model; (c) run the model and use the diagnosis results as a component of the Conservation Strategy; (d) identify data gaps and research needs; and (e) train the Technical Committee in the use of the model. These objectives support the overall purpose of creating a tool that can diagnose the relative contribution of various habitat factors for salmon performance across the WRIA, and evaluate the relative effectiveness of proposed conservation actions. The evaluation of alternative conservation actions through the 'Treatment' phase of EDT was not included in this stage of the strategic assessment, but is anticipated to be initiated following completion of the WRIA 8 Conservation Plan in January 2005.

In discussing the development, application, and results of the WRIA 8 EDT habitat model, it is important to keep in mind the context in which this model has been applied. The WRIA 8 EDT habitat model is nested within other analytical tools (VSP and Watershed Evaluation) that provide the strategic direction for WRIA 8's conservation efforts. EDT is applied within this context to develop hypotheses about habitat actions that will achieve the larger objective of creating and maintaining habitat conditions that support Chinook viability. Various reviewers (ISAB 2001, RSRP 2000) have provided guidance on the appropriate application of habitat models such as EDT, emphasizing the importance of 'hedging your bets' due to the inevitability of uncertainty and model bias. These critiques and guidance have informed the development of the WRIA 8 Conservation Strategy and the application of EDT within the Strategy. Key questions to consider when using any habitat or population model are as follows:

1. What data went into the model? Are model inputs based on observed data or expert opinion? Are there biases in the input data? How are errors propagated?
2. What is the basis for the equations on which the model is built? How certain are these relationships? What potential interactions exist within the sequence of modeled equations that might yield unintended effects?
3. What are critical physical and biological assumptions for the model? What biases are likely given these assumptions?

4. How sensitive is the model output to errors in input data? How sensitive is the model output to misspecifications of model parameters?
5. How have modeled predictions been field verified? Can some of the modeled outcomes be independently tested? How does the output from this model compare to that of other models, analyses, or other empirical data?

Finally, due to the varying purposes to which habitat models such as EDT have been applied throughout the Pacific Northwest, the W8TC believes that it is important to explicitly note the following:

- <u>EDT is not used to estimate salmon population abundance or to generate salmon population goals or planning targets</u>. While the EDT model outputs of *productivity, abundance*, and *diversity* have led to its use in identifying recovery targets in some river systems, it is important to recognize that the ***EDT population outputs are used by the model solely for the purpose of making relative comparisons about habitat actions and are not intended to be used as absolute numbers indicative of realistic salmon population outcomes***. While EDT outputs may be useful for estimating relative changes in population attributes, the EDT output values are not intended and should not be used as population goals.
- <u>EDT is not the principal analytical tool driving the Conservation Strategy</u>. The VSP Framework (based on guidance from NOAA Fisheries and described in Appendix C-1) provides the organizing structure and objectives for the Conservation Strategy. The watershed evaluation screen and EDT habitat model are used to generate hypotheses about habitat protection and restoration actions necessary to create and maintain habitat conditions that support viable Chinook populations in WRIA 8. ***In WRIA 8, EDT is nested within other analyses that help us understand the status of WRIA 8's populations, the risks faced by those populations, and identify habitat actions likely to reduce that risk***.

2 Methods

The EDT habitat model relates habitat conditions to species performance (a combination of the *productivity*, *abundance*, and *life history diversity* of the species) via a set of biological rules. The biological rules are mathematical relationships between habitat variables and the 'performance' of the focal species (Chinook and coho were the focal species in WRIA 8). These hypothetical biological rules are primarily based from peer-reviewed literature. The EDT method and the biological rules have been documented and critiqued elsewhere by the model developer (http://www.edthome.org/documentation.htm), other watersheds employing EDT, and scientific panels reviewing the EDT method (RSRP Dec 2000; ISAB 2000, Governors Salmon Office ISRP). Because of existing documentation this section will focus on the method WRIA 8 used to customize and apply the EDT model.

2.1 Customization of the EDT model for WRIA 8

The biological rules linking habitat conditions to species performance in river systems are described elsewhere, as noted above. However, the EDT model has not been applied extensively in lakes or saltwater environments. As part of WRIA 8's application of EDT, the model was customized for these environments and integrated with the river and stream model elements. This customization process for Lakes Washington, Union, Sammamish, the Ship Canal and Locks was completed by convening technical experts that have researched salmonid habitat use, behavior and survival in these areas. In the nearshore and estuary, the Tidal Habitat Model (THM) (Pentec, 2000) was revised based on input from a panel of scientists involved with nearshore and estuarine research and used to evaluate habitat conditions. The

THM model applies to juvenile Chinook only; adult relative survival determinations were based on previous EDT analyses across Puget Sound completed for the Washington Department of Fish and Wildlife. The lake and nearshore components are new portions of EDT and have therefore not had as rigorous a scientific review as the riverine portions of the model. The customization process and the resulting biological rules for the lakes, Ballard Locks, estuary, and nearshore are described in detail in Appendix C-4.

Lakes Washington, Sammamish, and Union were segmented for the EDT model by defining a set of polygons in a GIS coverage of the lakes. These polygons were defined by a qualitative shoreline assessment to identify the shoreline length of individual polygons, and extending the boundaries of the polygons from the shoreline to 1 meter in depth and from 1 meter to 12 meters in depth. The EDT lake model used these depth zones to delineate the primary habitats of immediate shallow nearshore and nearshore littoral utilized by chinook fry during the early lake phase. Life history trajectories were routed through the polygons and the Chinook fry exposed to the lake environmental attributes defined for each of the polygons.

The pelagic zones defined in Figure 1 are estimated areas of the lake used by Cedar River Chinook as they move off-shore in mid to late spring. The southern end of Lake Washington was given the highest ranks based on the proximity of this area of the lake to the mouth of the Cedar River. The area around Union Bay and Montlake Cut were high in priority because all fish use this area as the only migration route, both as smolts and returning fry. The areas around the mouth of the Sammamish River are lower in priority because of the prioritization of the North Washington tributary and Issaquah runs, and because the fish that enter Lake Washington in this area tend to be older and spend less time in the immediate nearshore area of the lake. In Lake Sammamish, no comparable study on nearshore landuse existed, so segmentation was done using aerial photographs and substrate data collected by King County.

In Lake Washington, the shoreline delineation was based on an assessment of upland habitat near the lake, and a qualitative evaluation of bottom substrate type (Toft 2001). For both lakes, depth contours for 1 m and 12 m were based on bathymetric data collected by King County (unpublished King CountyGIS data). This data was collected by boat-towed hydroacoustics, and is least accurate at the immediate shoreline. The area of the 0-1 meter polygons is probably overestimated, but on a lake wide scale, this error is insignificant.

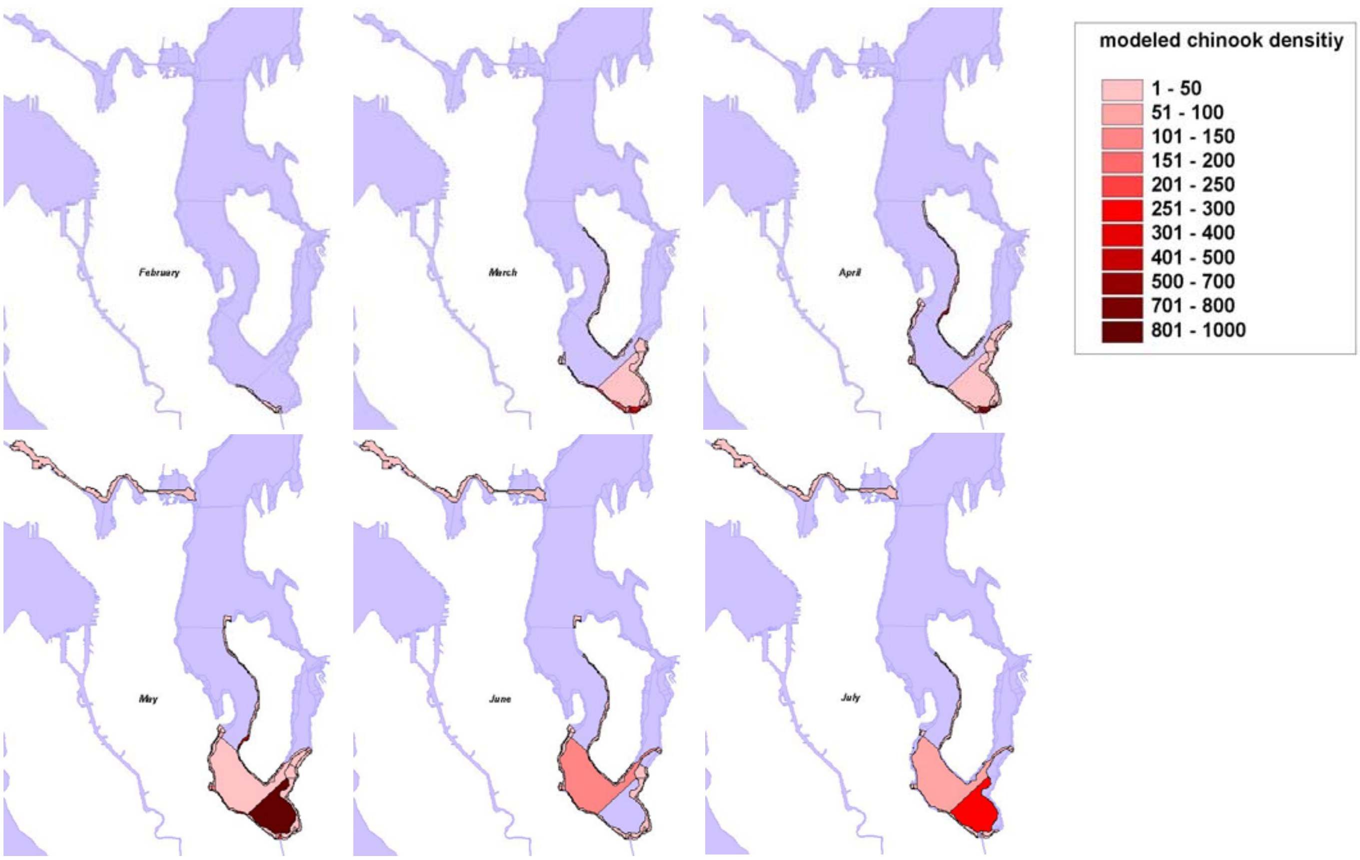
2.2 Life History Trajectories - Population Structure and Timing

Information about life history trajectories within WRIA 8 were developed based on several reports describing juvenile and adult Chinook habitat use and timing (see, for example, Seiler et al, 2003; Burton et al, 2002). Smolt trapping studies, PIT tagging, and snorkel surveys were the main source of information about juveniles, while the spawner surveys provided information about the timing and distribution of returning adults.

Trajectories in the limnetic and littoral areas of the Ship Canal, Lake Washington and Lake Sammamish were determined based on studies of juvenile fish distribution conducted by the University of Washington, the US Fish and Wildlife Service, and WDFW (see, for example, Tabor and Piaskowski, 2002; Fresh et al 2001). Based on these studies and input from technical experts, it was hypothesized that 75% of Cedar River Chinook enter the lake as fry, while 25% remain in the river and migrate as smolts. The fry migrant life history trajectory uses the south end of Lake Washington for rearing, and then migrates out of the system through the Ballard Locks by mid-June. The template condition is believed to be approximately an equal allocation of lake-rearing and in-stream rearing in the Cedar River. However, the EDT model does not accommodate separate life history trajectory assumptions for template versus current conditions in the same model run. Due to time and budget constraints the template life history trajectory for the Cedar population was assumed to the be same as the current trajectory, with 75% rearing in the lake and 25% rearing in the Cedar River. Chinook fry rearing in the lake remain along the shorelines of the south end of the lake from approximately February through May. Out-migrants then travel along the shallow shoreline and limnetic areas (>1 meter depth) during May and June as they move north toward the Montlake Cut and Ballard Locks.

In the North Lake Washington tributaries, smolt trapping information indicates greater than 90% of juveniles migrate out of their natal streams as smolts and enter the north end of Lake Washington between May and June (Seiler et al, 2004). NLW Chinook enter Lake Washington as smolts rather than fry, and spend less time in the lake than Cedar River juveniles. The relative use of limnetic and littoral habitat use by NLW juvenile outmigrants is uncertain, but assumed that there is relatively greater use of limnetic habitat compared with Cedar River juveniles. Both groups exit through the Ballard Locks, with outmigration peaking during May and June and completed by the end of July.

Figure 1: Lake Washington Model Trajectories for Cedar Chinook Out-Migrants



The highly modified nature of the Sammamish River channel and the high summer temperatures results in the need to tailor the life history trajectories based on smolt trapping and PIT tagging at the Ballard Locks. Juvenile outmigration from Bear Creek to the Ballard Locks was modeled based on observed data (Jeanes 2002), with earlier March migrants taking longer to reach the Locks (6 weeks) than later May migrants (15 days). Returning adults wait at the Locks for temperatures below 20 degrees C and then move quickly (2 weeks on average, with some taking as long as 4 weeks) through the system to reach the Bear Creek spawning grounds by the end of September and the Issaquah spawning grounds by the first week in October.

Life history trajectories in the Ship Canal and Ballard Locks were modeled based on PIT tagging (DeVries, 2002) of juvenile fish and observations of adult returns at the Locks. More information about the potential trajectories used by salmon maneuvering through the Ballard Locks facilities is available in Appendix C-4 of this report.

2.3 Template or “Historic” Habitat Conditions

Template conditions are used to establish baseline conditions against which current conditions can be compared. In most cases historic conditions (approximately 1850 or pre-European settlement) are used to establish a useful baseline condition for comparison. In WRIA 8, the extensive hydrologic ‘re-plumbing’ of the system exacerbates the already challenging task of describing historic pre-European settlement conditions. As described in Chapter 3, WRIA 8 was historically connected to the Green River (which was also historically connected to the White River) via the Black River at the south end of Lake Washington. The current outlet at the Ballard Locks was historically a small intermittent drainage from Lake Union to the mudflats of Salmon Bay, with no connection to the Lake Washington system. After the construction of the Locks, the Cedar River was re-directed through a one-mile long channelized segment into Lake Washington, and the level of Lake Washington dropped approximately 9-11 feet. In addition, multiple drainage ‘improvement’ projects between 1918 and the 1960s have extensively straightened, channelized, and disconnected the Sammamish River from wetland complexes in the Sammamish Valley between Lake Sammamish and Lake Washington. Given all of these alterations, the template condition modeled in EDT could be best summarized as historic habitat conditions with current hydrologic routing. That is, we assumed a template condition with the Cedar River flowing into Lake Washington and out to Puget Sound via the Ship Canal to the Salmon Bay estuary, lake levels approximately 9-11 feet below true historic levels, and a shortened Sammamish River. The assumption that the current hydrologic routing of the system (and the resulting disconnection of WRIA 8 salmon populations from the Green River and White River populations) is sufficient to support the viability of WRIA 8 Chinook populations is consistent with the PSTRT’s independent population document (PSTRT 2001), and has been shared with the PSTRT and NOAA Fisheries in 2003.

2.4 Current Habitat Conditions

Figure 2. Lake Washington Segmentation and Prioritization Areas

Documentation of current habitat conditions (t ... d in the EDT Method (Mobrand, 2001 and Mob ...) reports and studies that were reviewed by the ... inputs and a summary of data sources were provided to a panel of technical experts for each sub-area of WRIA 8. During 2002 and 2003, over 100 local experts from 35 entities (agencies, jurisdictions, consultants, non-profits) were invited to participate in a workshop to review the habitat data as well as the segmentation of stream reaches. At these workshops participants provided new data sources, refined the ratings based on best professional judgment and field experience in the stream, or estimated habitat ratings based on similarities to other systems. As a result of this process each habitat rating was assigned a level of confidence rating ranging from 1 (published study) to 5 (educated guess). In the few situations where there was strong disagreement about habitat ratings, the consultant conducted a sensitivity analysis to determine the impact of using different ratings. Data uncertainties, the results of sensitivity analyses, and additional sensitivity analyses that are necessary will be discussed as part of the discussions section of this report.

Model inputs for the Issaquah and May Creek systems were not thoroughly peer reviewed as part of this process due to time constraints and were reviewed in October 2004. Updates to the model outputs based on this review are underway.

2.5 WRIA 8 Modifications to EDT Model Outputs

In addition to the customization of the EDT model for lake, estuarine, and nearshore environments, the W8TC modified standard EDT outputs to increase our confidence in the results, as well as the applicability of the information to the WRIA 8 Conservation Strategy.

2.5.1 Modifications to Geographic Priorities

As described in the Conservation Strategy (Chapter 4) and in Appendix C-2, the Watershed Evaluation combines information about relative Chinook use (abundance and frequency of use) with an assessment of relative watershed condition to develop tiers of sub-areas used by each of the three Chinook populations in WRIA 8. The results of the EDT diagnosis phase were used within each of these Tier 1 and Tier 2 sub-areas to identify key life stages and habitat attributes that should be protected or restored. This lead to protection and restoration priorities within each Tier 1 and 2 sub-area, rather than a focus on only the high potential reaches identified by the EDT model. For example, the EDT results for the Bear Creek system identify the highest protection potential in the lower reaches of Bear Creek, with relatively lower potential for Cottage Lake Creek (a tributary of Bear Creek). However, because both the Bear Creek and Cottage Lake Creek sub-areas are considered to be Tier 1 areas protection priorities were developed within each sub-area.

Although Tier 3 sub-areas were modeled using EDT, the Technical Committee did not use the EDT diagnosis results to develop reach-level protection and restoration recommendations for these systems because of the infrequent use of these systems by Chinook. As described in the Conservation Strategy, basin-wide recommendations focused on maintaining water quality and hydrologic processes were generated due to the downstream impact of these tributary systems on Tier 1 and Tier 2 sub-areas.

2.5.2 Modifications to Protection and Restoration Potential for each Reach

The EDT habitat model provides estimates of the relative potential of each reach (normalized by length) to protect or restore Chinook performance. Salmon ‘performance’ in EDT combines *productivity*, *abundance*, and *life history diversity* model outputs. However, the standard EDT reach prioritization combines the *rank* of each reach for each of the three model outputs. The W8TC felt this approach obscured strategically important differences in relative potential between reaches – that is, two hypothetical reaches could be ranked 1 and 2, but reach 1 could have three times the potential for each of the model outputs. To remedy this situation, the W8TC normalized the results for each model output (abundance, productivity, and life history diversity) on a scale of 0 to 1 so that the model outputs could be combined and the relative potential between reaches could be evaluated. This modification resulted in slightly different rankings of stream reaches in some stream systems.

2.5.3 Protection of In-stream Habitat Attributes

The W8TC adapted the EDT protection priorities so that high quality instream habitat conditions could be identified and protected at the reach scale. Adaptations to the model results were necessary because the protection potentials in EDT are driven primarily by key life stages such as egg incubation that are most impacted by water quality and flow attributes. These survival attributes result more from upstream landscape-level conditions than from conditions within the high-priority reach. The Technical Committee identified landscape-level protection hypotheses in response to these findings, and these recommendations are a fundamental part of the Conservation Strategy. However, WRIA 8 is also looking to use these EDT results to prioritize potential preservation actions within reaches, and the direct application of the EDT Chinook protection potentials does not provide a clear 'diagnosis' of reaches that should be protected due to the prevailing influence of water quality and flow factors that result from watershed-wide conditions. In order to address this issue, the WRIA 8 Technical Committee made basin-wide recommendations based on the EDT diagnosis, but used EDT in a limited role to organize and compare reach-specific information about riparian habitat diversity factors (riparian function, LWD, and channel connectivity) that are relatively intact (compared to template conditions) and should be protected. These habitat-forming factors were selected based on their importance for multiple salmonid species, and are more consistent with WRIA 8's objective of protecting and maintaining high-quality functioning habitat independent of its use by a particular species.

2.6 Interpreting the EDT Diagnosis Results

In addition to the prioritization of reaches according to protection and restoration potential, EDT produces what is commonly referred to as a 'consumer reports diagram' that diagnoses the relative impacts of restoring various survival attributes for salmon life stages. As described in the EDT method documentation and summarized in Figure 3, each of these 'Level 3' survival factors (ie habitat diversity, sediment load, flows) represents interactions of individual habitat attributes (referred to in the EDT model as Level 2 habitat attributes). The W8TC used the following steps to 'drill-down' into the model results in order to develop specific hypotheses about protection and restoration priorities. As shown on Figure 4, this drill-down process essentially reverses the steps used to characterize habitat conditions and diagnose habitat restoration priorities.

<u>Restoration 'Drill-Down'</u> (see Figure 3):

1. Prioritize reaches based on normalized EDT model restoration outputs
2. For each reach, look at key (the top 2 or 3) life stages by using the life stage ranking. The life stage ranking results from multiplying the productivity change percentage by the percentage of life history trajectories affected.
3. For each key life stage, identify level 3 survival attributes with the largest relative impact on the life stage
4. Using the EDT rules, identify the primary and modifying level 2 attributes for each key life stage
5. Using the model input data in the Stream Reach Editor, identify the relative alteration of the level 2 attributes from template conditions
6. Compare the EDT attributes with the Watershed Evaluation assessment of watershed condition (described in Appendix C-2) to determine if the EDT diagnosis of in-stream conditions reasonably reflects landscape conditions.

7. Develop hypotheses about landscape- and reach-level attributes that should be restored to improve key Level 2 habitat attributes.

Step 1: Prioritize reaches based on normalized EDT outputs (see Section 2.5.2)

Step 2: Identify key life stages using 'life stage rank' that combines potential productivity change with % life history trajectories that are affected

Step 3: Identify survival attributes that have the greatest impact on the life stage

Step 4: For each survival attribute identified in Step 3, review Level 2 attributes to identify key habitat attributes that drive survival for the life stage (e.g. the impact of habitat diversity on fry colonization is a combination of LWD, channel connectivity, and riparian function)

Step 5: Refer to Stream Reach Editor to see current vs template habitat ratings for attributes identified in Step 4.

Step 6: Compare EDT diagnosis with watershed evaluation

Step 7: Develop hypotheses for restoring the reach-level habitat attributes identified in EDT and the watershed factors that create these attributes

Species/Component:	Fall Chinook
Restoration Potential:	Current Conditions versus Historic Potential
Restoration Emphasis:	Restoration or maintenance/improvement of historic life histories

Cedar River - Fall Chinook

Geographic Area:	Cedar-4	Stream:	Cedar River
Reach:	Cedar River from SR 169 Bridge (RM 4.2) to upstream of Landslide (RM 4.7)	Reach Length (mi):	0.50
		Reach Code:	Cedar-4

Restoration Benefit Category:1/	C	Productivity Rank:1/	21	Potential % change in productivity:2/	1.0%
Overall Restoration Potential Rank:1/	20	Average Abundance (Neq) Rank:1/	21	Potential % change in Neq:2/	3.6%
(lowest rank possible - with ties)1/	37	Life History Diversity Rank:1/	19	Potential % change in diversity:2/	1.4%
Preservation Benefit Category:1/	C	Productivity Rank:1/	29	% loss in productivity with degradation:2/	-1.1%
Overall Preservation Rank:1/	24	Average Abundance (Neq) Rank:1/	20	% loss in Neq with degradation:2/	-5.0%
(lowest rank possible - with ties)1/	37	Life History Diversity Rank:1/	26	% loss in diversity with degradation:2/	-1.8%

Life stage	Relevant months	% of life history trajectories affected	Productivity change (%)	Life Stage Rank	Change in attribute impact on survival															
					Channel landscape	Chemicals	Competition (w/ hatch)	Competition (other sp)	Flow	Food	Habitat diversity	Harassment/poaching	Obstructions	Oxygen	Pathogens	Predation	Sediment load	Temperature	Withdrawals	Key habitat quantity
Spawning	Oct-Nov	1.6%	-5.8%	5							●	●			●	●		●		
Egg incubation	Nov-May	1.6%	-17.5%	3	●													●		
Fry colonization	Apr-May	75.0%	-0.5%	1	●				●		●					●				●
0-age active rearing	Mar-Oct	17.4%	-0.3%	6	●						●				●	●		●		●
0-age migrant																				
0-age inactive																				
1-age active rearing																				
1-age migrant																				
1-age transient rearing																				
2+-age transient rearing																				
Prespawning migrant	Sep-Oct	91.8%	-0.2%	4					●		●	●			●	●		●		●
Prespawning holding	Oct-Nov	1.6%	-18.1%	2					●		●	●			●	●		●		●
All Stages Combined		91.8%																		

1/ Ranking based on effect over entire geographic area.

2/ Value shown is for overall population performance.

Notes: Changes in key habitat can be caused by either a change in percent key habitat or in stream width.

Potential % changes in performance measures for reaches upstream of dams were computed with full passage allowed at dams (though reservoir effects still in place).

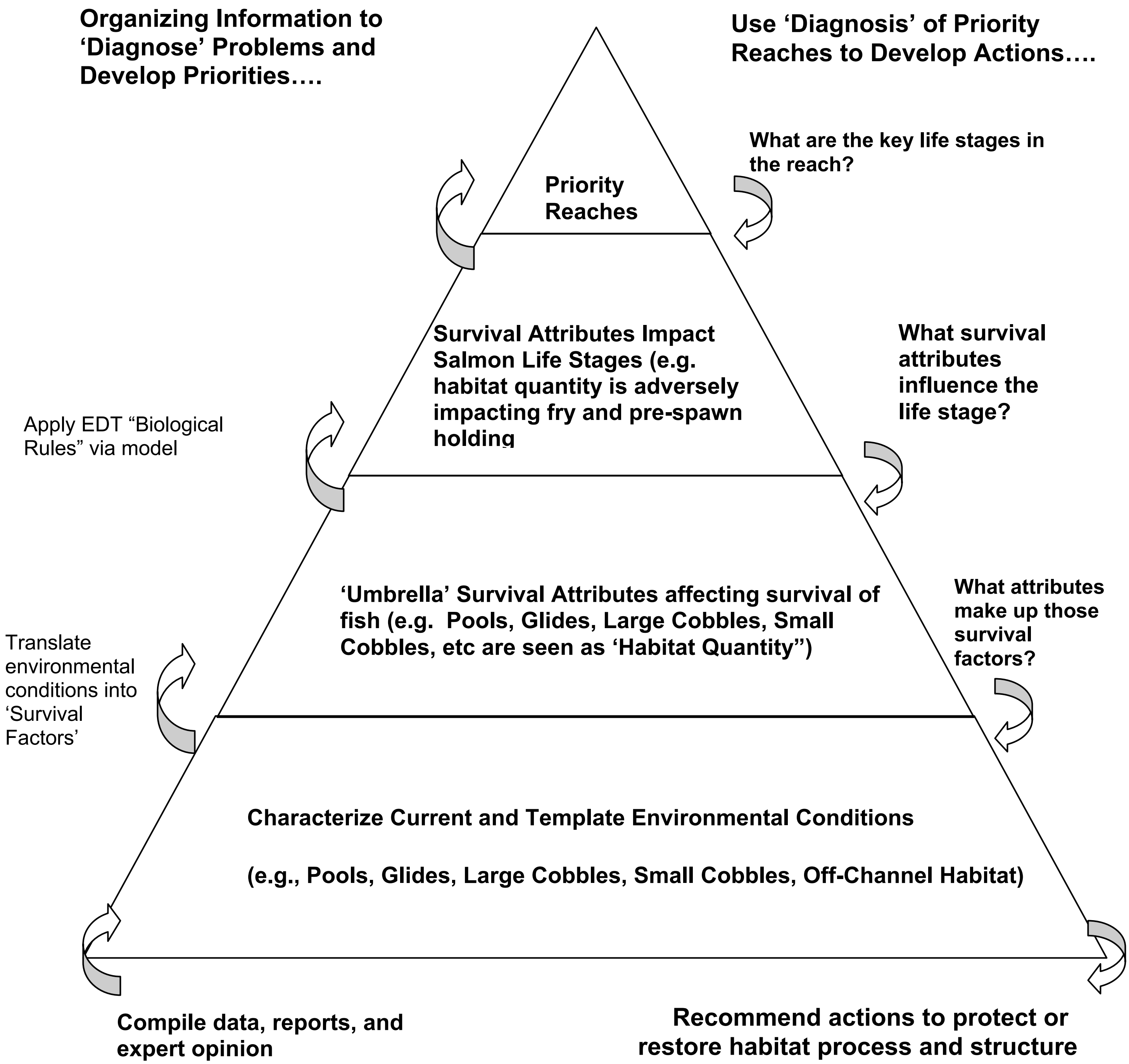
KEY

NA = Not applicable

	Loss	Gain
None		
Small	•	•
Moderate	●	○
High	⬤	◯
Extreme	⬤	◯

Figure 3: How to Interpret the EDT Diagnosis 'Consumer Reports' Diagram

Figure 4: Process Used to “Drill-Down” into EDT model to identify restoration actions



Protection 'Drill-Down':

1. Prioritize reaches based on normalized EDT model protection potentials
2. Identify the life history stages that are most affected in each reach
3. For each key life stage, review the EDT rules to identify level 3 attributes that significantly impact the life stage
4. Using the EDT rules, identify the primary and modifying level 2 attributes for each level 3 survival factor
5. Identify basin-wide recommendations based on the key level 2 attributes
6. For reach-specific protection recommendations, compare current versus template habitat ratings for the habitat diversity factors: large woody debris, hydromodifications (channel connectivity), and riparian function (riparian vegetation, overbank flows, and groundwater interactions).
7. Rank reaches with the least altered habitat-forming factors for protection.

3 Results

The application of the EDT habitat model diagnosis phase to WRIA 8 produced the following information:

- Relative sub-area restoration potentials across populations (ie Lake Washington vs Sammamish River vs Cedar River)
- Relative basin-level restoration potentials within each population
- Relative reach-level protection and restoration potentials within each population
- Diagnosis of key life stages and the relative importance of habitat attributes in achieving the protection or restoration potential.

The geographic restoration potentials and a summary of the diagnosis results in each sub-area are presented in the Chapter 4.

As noted in the Methods section, EDT was applied to the Tier 3 streams but the diagnosis results were not included in the Technical Committee's analysis.

3.4 Areas Used by Multiple Populations

As noted in the Methods section, the customized EDT lake habitat model is built based on the hypothesis that predation on juveniles is the key factor impacting salmonid survival in the lake environment, and the effectiveness of predators is driven by habitat factors. Although the key predators vary over the juvenile Chinook migration period (ie primarily cutthroat in Lake Washington during February-May, switching over to bass in the Ship Canal during May-June when bass metabolism increases in response to higher water temperatures, the key habitat factors that modify predator efficiency are the same. Restoration of lake shoreline (referred to in the model as 'bank type') from hardened (bulkheaded or rip-rapped) to exposed beach or softened bank conditions is hypothesized to be the most effective means of reducing predation on juvenile Chinook and coho in the lake environment. Predation would also be reduced through increased LWD and shoreline vegetation that provide cover for juvenile Chinook. Based on lake modeling results it is hypothesized that restoration of lake segments adjacent to stream mouths will have higher benefit to Chinook. Because NLW juvenile Chinook enter the lake as smolts and use the lake primarily for migration rather than rearing, overall lake restoration potentials tend to be weighted toward benefits to the Cedar River population. Areas with the highest restoration potential for WRIA 8 Chinook are (listed in priority order):

- *Section 1- Near Mouth of Cedar*
- *Section 2 – South end of Mercer Island, mouths of Mapes and May Creeks*
- *Section 5 – Montlake Cut & Union Bay*
- *Section 7– North End of Lake Washington at the mouth of Sammamish River, mouths of McAleer and Lyon Creeks*
- *Section 3 – South of I-90, East and West Mercer Island channels, Seward Park and Mercer Slough*
- *Section 4 – Area between 520 and I-90 bridges*
- *Section 6 – North of 520 bridge, includes Sand Point, Thornton Creek, Yarrow Creek, and Juanita Creek*

The customized EDT results for the nearshore and estuary lead to the hypothesis that the greatest restoration potential is for the Salmon Bay estuary. Removing all mortality at the Ballard Locks resulted in a relatively slight increase in population abundance, as the model assumes high juvenile survival at the Locks based on recent passage improvements. Restoring nearshore areas resulted in a similarly low increase in modeled population abundance for WRIA 8 Chinook populations. Within the nearshore area, restoration of creek mouths is hypothesized to have a high restoration potential.

4 Discussion

4.1 Linking Habitat Changes to VSP

As noted by McElhany et al (2000), “viable salmonid populations clearly require high quality habitat”, but the VSP guidance from NOAA Fisheries “does not attempt to establish the relationship between particular habitat attributes and population viability.” Suitable habitat conditions are necessary but not sufficient for population viability, due to the influence of external factors such as harvest and hatchery management. Because of these external influences on population viability, the habitat actions identified in the Conservation Strategy are intended to create and maintain habitat conditions that will support population viability.

In order to develop recommendations about how habitat should be protected or restored to support Chinook viability, the Technical Committee developed Figures D-__ and D-__ to describe our hypotheses about the relationships between watershed factors, in-stream habitat conditions, Chinook life stages, and population attributes. The EDT diagnosis generates hypotheses about key life history stages that would benefit from the protection or restoration of key in-stream habitat attributes. These in-stream attributes are created and maintained by watershed level factors. The Technical Committee used the watershed evaluation to help identify watershed processes and landscape conditions that should also be protected or restored.

The Technical Committee focused on protecting and restoring Chinook productivity for key life stages identified through EDT. By developing recommendations intended to impact productivity in Tier 1 and Tier 2 sub-areas, the Technical Committee hypothesizes that abundance, spatial distribution, and diversity will be improved as well. For example, the EDT diagnosis hypothesizes that the productivity of the Cedar Chinook population will increase if pool habitat areas on the mainstem Cedar River are restored for juvenile rearing (specifically the fry colonization life stage). By increasing habitat for juvenile rearing, it is also hypothesized that more juveniles will rear in the mainstem river rather than migrating as fry to Lake Washington. This would create habitat conditions that support improved life history diversity as well as increased productivity of Cedar Chinook. Similarly, actions that improve habitat conditions for Chinook fry and pre-spawning migrants in Bear Creek are hypothesized to increase the productivity of the Bear Creek system. This will likely indirectly result in increased spatial distribution of the population high-quality habitats in Bear Creek reach capacity and returning adults begin to use other NLW tributaries.

At this time the Technical Committee has not evaluated the relative potential of specific habitat actions to protect or restore key habitat conditions that support viability. The Treatment phase of the EDT habitat model is intended to provide a relative evaluation of the effectiveness of conservation actions, and may be applied to support Steering Committee decisions regarding proposed actions.

Additional discussion of habitat changes that promote improvements in population viability is included in Section 7 of the VSP Framework (Appendix C-1).

Figure 5: Interaction of human activities with riverine/estuarine ecosystem. Human activities influence salmon populations indirectly through influences on biophysical processes and alterations of habitat patterns, and directly through influences on population production and diversity. **Adapted from Martin, *An Ecosystem Strategy For Restoring Threatened/Endangered Salmon In King County*, *June 10, 1999***

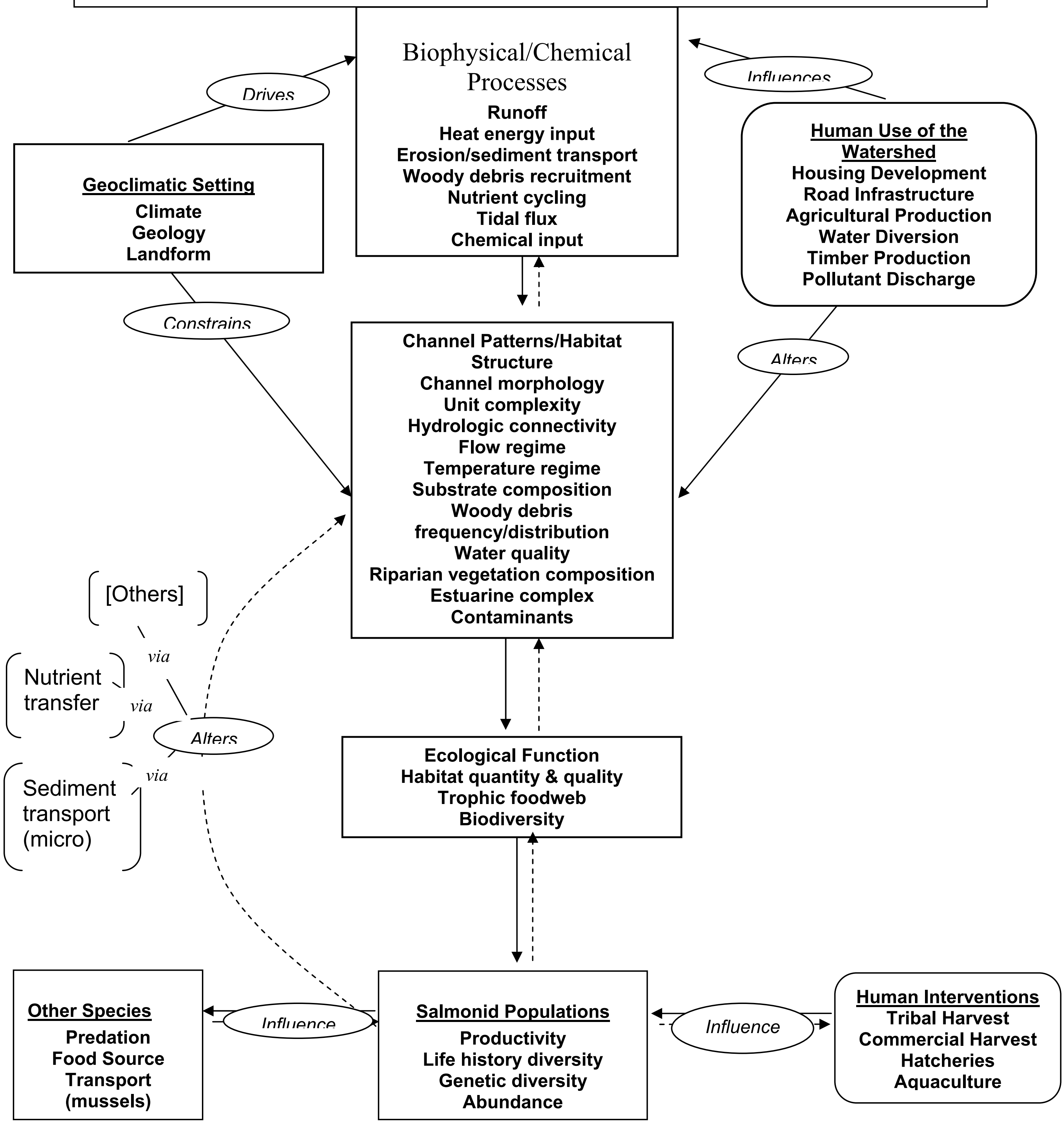
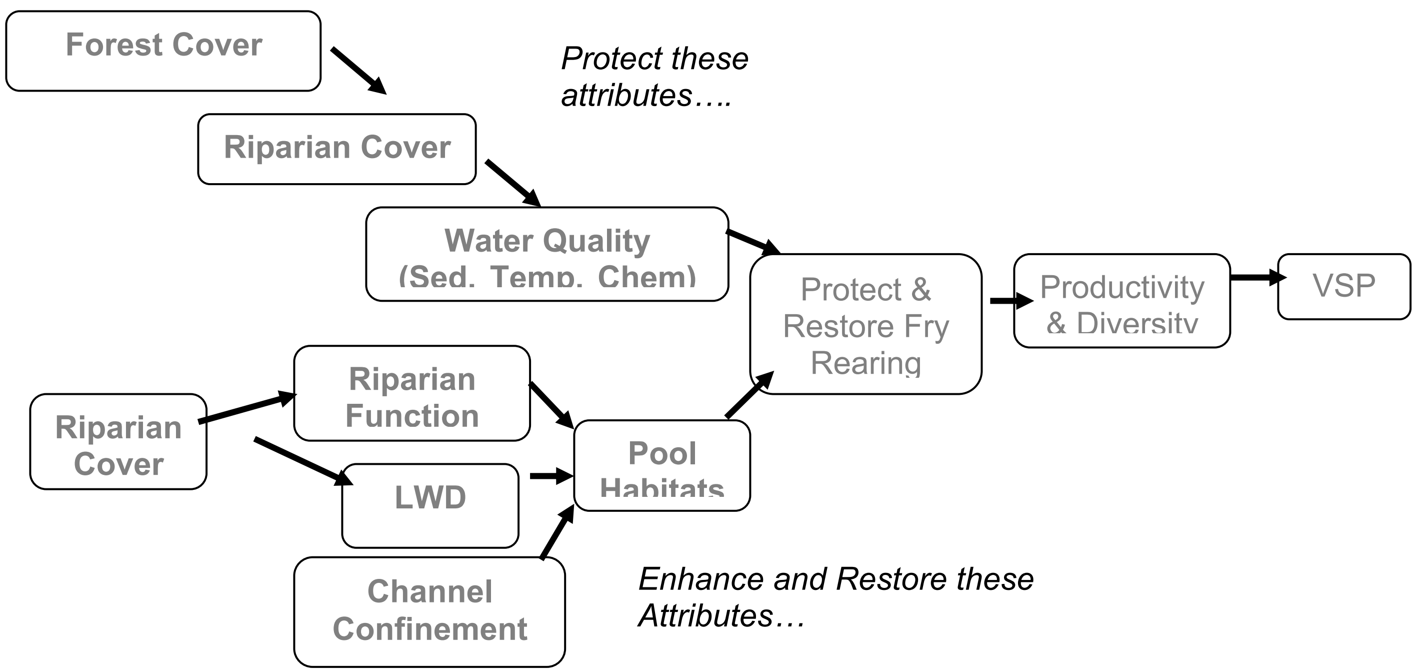
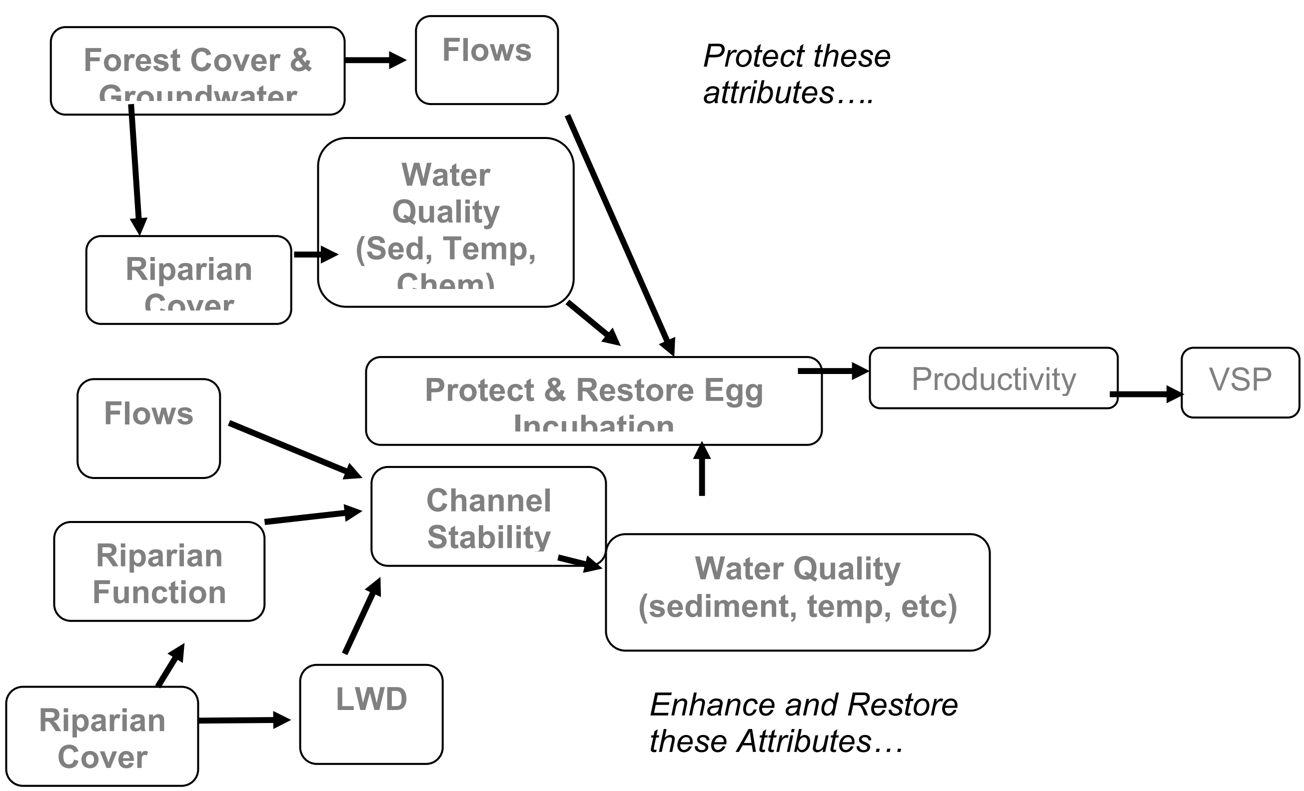


Figure 6: Building Conservation Hypotheses Linking Habitat Changes to Population Attributes for Chinook Life Stages (Pre-spawning holding and migration to be added)





4.2 Sources of Uncertainty and Model Bias

When using a model to support decisions it is critical to 'hedge your bets' due to uncertainties and biases that are inherent in any attempt to model dynamic and complex natural systems. This section will describe how the Technical Committee addressed these uncertainties and biases in the application of EDT.

4.2.1 Model Inputs - What data went into the model? Are model inputs based on observed data or expert opinion? Are there biases in the input data? How are errors propagated?

As part of the EDT habitat characterization effort, data inputs were ranked on a scale of 1 (observed data) to 5 (expert opinion).

As is apparent from the information presented in Section 2, WRIA 8 is one of the more data-rich WRIAs in Puget Sound. The EDT process provided the opportunity to compile this information into one framework, and convene technical experts from various disciplines to discuss the data. In cases where observed habitat data was not available, the Technical Committee relied on the best professional judgment of the expert panels. The workshop format also enabled the panel members to question one another about underlying assumptions and their first-hand knowledge of the areas in question. This type of conversation provided some calibration among the experts, but the Technical Committee acknowledges that this type of expert-driven Delphi approach to habitat characterization is prone to subjective data inputs and interpretation of the habitat rating criteria that can bias the input data.

In order to reduce bias in the input data, it is necessary to increase the amount of observed data in the model, focusing on the key habitat attributes in the model. As recommended by the Recovery Science Review Panel (RSRP, December 2000), the models should focus on key relationships as well as the need to locate aspects of the model that are most likely to expand error in the results. Based on Technical Committee review of the model rules and outputs for WRIA 8, the key habitat attributes 'driving' the model in the river and stream systems are:

- Riparian function (overbank flows, vegetation, and off-channel area)
- Large Woody Debris
- Habitat area (total area by type, and the relative proportion of each type)
- Channel connectivity (hydromodifications)
- Flows (flashiness and low flows)
- Sediment load (fine sediment and turbidity)
- Water quality (temperature, dissolved oxygen, and metals)

Of the habitat attributes listed above, direct salmonid survival relationships are best described for temperature (maximum), bed scour, habitat types and area, and fine sediments.

Key research needs are riparian function and sediment budgets and water quality
Specific habitat data needs for key sub-areas are listed in Table 1 below.

Table 1: WRIA 8 EDT Habitat Characterization Data Gaps for Rivers and Streams

Stream System	Data Gap
All Sub-Areas	• Hyporheic flows - Distribution of groundwater springs and upwellings • Riparian function • Bed Scour • Hydromodifications • Flows • Sediment loading budgets (includes fine sediments and embeddedness as well as sediment sources and transport rates) • Water quality – toxicants in water column and sediments
Cedar River	• Bed scour
Cedar River Tributaries	• Habitat types and in-stream structure
Bear Creek	• Bed scour • Community effects – predation, hatchery influences, species introductions
Kelsey Creek	• Bed scour • Hydromodifications • Water quality (temperature and dissolved oxygen) • Community effects – predation, hatchery influences, species introductions
Issaquah Creek and May Creek	• Additional review of all habitat data ratings • Bed scour

In evaluating model inputs, there is a tendency in the EDT process to focus solely on the characterization of habitat conditions. While important, it must be kept in mind that the model produces results by 'exposing' model fish to habitat conditions through the life history trajectories. Significant bias or errors could result from a hypothetical life history trajectory that inaccurately 'exposes' fish, either spatially or temporally. Although WRIA 8 has smolt trapping data for the Cedar River, Bear Creek, and Issaquah Creek, along with some focused snorkel surveys of juvenile salmonids, there is uncertainty about the timing and distribution of juvenile Chinook within these systems, and this uncertainty could introduce errors in the model results. The effectiveness monitoring program described in Chapter 6 proposes continued smolt trapping, PIT tagging, and snorkel surveys that will reduce the uncertainty about life history trajectory model inputs.

Finally, there are uncertainties about data inputs for template conditions. While some historic information was available to inform assumptions about template conditions, this data could be improved based on historic habitat surveys such as those conducted by Collins et al (2003) for WRIAs 7 and 9, among others. The Technical Committee does not expect that this information will result in significant changes to the current recommendations – for example, increased habitat diversity and off-channel habitat areas for juvenile rearing would still emerge as a key restoration recommendation on the Cedar, and re-meandering of the Sammamish River would be a primary focus of the NLW restoration strategy. However, improved understanding of historic habitat conditions would be extremely helpful for the design of restoration projects in these areas.

4.2.2 Model Equations - What is the basis for the equations on which the model is built? How certain are these relationships? What potential interactions exist within the sequence of modeled equations that might yield unintended effects?

EDT uses hypotheses about the relationship between key environmental conditions and species performance based on peer-reviewed literature values (available at http://www.edthome.org/). These species-specific hypotheses are captured in a series of mathematical equations referred to as 'biological rules' within the EDT habitat model. As noted by the RSRP (2001), many of the biological rules in EDT 'are simply not known and cannot be adequately known'. In response to the reality that some relationships are known to be important for salmon life stages but are not thoroughly understood and quantified, we have reduced our reliance on uncertain model relationships by (1) using EDT within a nested analytical framework and (2) focusing on the appropriate use of EDT as a scientific (rather than statistical) model to make relative comparisons rather than absolute determinations.

Nested Analytical Framework

The EDT diagnosis of habitat conditions is nested within the VSP Framework and the watershed evaluation framework. The WRIA 8 Conservation Strategy is primarily driven by the assessment of the status of each Chinook population in WRIA 8 and the risk posed to the population attributes of each population. In order to identify habitat protection and restoration priorities, the watershed evaluation was used to stratify sub-areas used by an individual population and identify potential protection and restoration strategies based on watershed conditions such as the level of forest cover and impervious surface. The EDT habitat model was then used within each sub-area to identify hypotheses about habitat attributes that should be protected or restored, and the geographic locations with the highest potentials for protection or restoration of key life stages. This nested analysis results in a Conservation Strategy that includes hypotheses about habitat-forming processes that are not explicitly included in the EDT diagnosis (ie maintaining hydrologic integrity by protecting forest cover and groundwater recharge areas), as well as the recognition of the importance of habitat areas that are not considered a high priority in the EDT model (for example, the importance of Little Bear, North, and Evans Creeks in expanding the spatial distribution of the North Lake Washington population to reduce the risk of having the population focused almost entirely in the Bear / Cottage Creek system).

EDT as a Scientific Model

When evaluating the certainty of relationships in EDT, it is important to consider the intended use of the model. As noted by the Northwest Power Planning Council's Independent Science Advisory Board (ISAB 2001), EDT has never been intended to judge absolute salmonid performance (as measured by abundance, productivity, and life history diversity). Rather, EDT is a scientific model to develop hypotheses about the relative impact of relationships that are known to be important for Chinook but not necessarily quantified or quantifiable. This hypothesis-driven approach requires a robust monitoring and evaluation program to test hypotheses about key relationships in the model. WRIA 8's approach to reducing uncertainties about these key relationships will be described in more detail in this section, as well as in the Monitoring and Evaluation Chapter (Chapter 6).

Uncertain Model Relationships in the Customized Areas of WRIA 8

In areas such as the lakes and Ship Canal where the Technical Committee has developed biological rules to customize the EDT model, there is relatively greater uncertainty about model equations and the interactions of multiple habitat attributes and species. In keeping with the recommendations of the RSRP, the lakes experts focused their attention on key 'driving variables' that are believed to be the essential descriptors of Chinook performance in the lake environment. An early conclusion by the lakes expert panel was that the predominant cause of mortality for juvenile salmon in the lakes is predation. It was also clear from recent studies in Lake Washington (Tabor, 2003) that both abundance of predators and the vulnerability of the prey are affected by factors such as bank type, substrate, and predator species composition. WRIA 8 partners continue to participate in research to improve WRIA 8's understanding of food web dynamics, the role of predators and exotic species, and salmonid behavior in these areas.

In the nearshore and estuary there are uncertainties about habitat conditions, fish use of these habitats, species interactions, and the use of these areas by salmonids from other WRIAs. In light of these uncertainties the Technical Committee's recommendations focus on experimental actions that will expand WRIA 8's understanding of nearshore and estuary conditions while protecting and restoring ecosystem processes and structures such as sediment supply, water quality, overhanging vegetation, tributary mouths, and 'pocket' estuaries.

Uncertainties about Species Interactions
Interactions between species (both native and introduced) are a critical uncertainty in the EDT model framework. This results from the known high rates of juvenile mortality in the lakes, the fact that the nearshore and estuary are used by multiple fish species (including salmonids from other WRIAs), and the highly altered landscape in these areas. Food web dynamics and the impacts of non-native fish species is a focus of on-going research in the lakes by King County, the University of Washington, and others, and the linkages between predator populations such as cutthroat trout and habitat conditions in small tributary streams that are not frequently used by Chinook (ie McAleer, Lyon, Juanita) requires additional research.

Population interactions in the river and stream EDT model are fairly simplistic and would benefit from additional research on food web dynamics in response to changing habitat and community conditions.

Uncertainties about Pre-Spawning Mortality
Symptomatic pre-spawning mortality has been documented in WRIA 8 coho populations beginning in the late 1990s. Pre-spawning mortality is likely to be occurring in Chinook as well (CITE – 2003 spawner surveys), although the symptomatic behaviors (ie disorientation) have not been documented to date. WRIA 8 stakeholders are participating in investigations of potential water quality causes to pre-spawning mortality being conducted by the Fish Neurobiology and Development Group at the NOAA Fisheries Northwest Fisheries Science Center. For examples of the symptomatic behaviors associated with pre-spawning mortality, see http://www.nwfsc.noaa.gov/research/divisions/ec/ecotox/movies/cohoPSM.cfm. Given uncertainties about the cause of pre-spawning mortality and other potentially related chronic effects of degraded water quality on predator avoidance, the EDT model rules have not been updated to include pre-spawning mortality and sub-lethal effects, and the model results therefore cannot be expected to reflect the full extent of likely water quality impacts on salmonids. In the face of this uncertainty, the Technical Committee has recommended improved management of stormwater runoff throughout the WRIA, even though water quality problems are not considered severe in the EDT diagnosis for most streams.

Finally, the impacts of global climate change on aquatic habitat conditions are a significant source of uncertainty that is not addressed in the EDT habitat model. Potential impacts of climate change include increased winter flooding, decreased summer and fall streamflows, and elevated in-stream and estuarine temperatures. The Technical Committee will continue to track research developments from the University of Washington's Climate Impacts Group (http://www.cses.washington.edu/cig/) and others, and will seek opportunities to link our analytical tools to larger scale climate models.

Model Relationships with Relatively Higher Confidence
Although there are multiple areas of model uncertainty that can and should be identified, it is worth noting areas of relatively high confidence. Figure 7 shows habitat attributes that drive key life stages in the EDT model, along with potential habitat actions that target habitat variables that are relatively certain to protect or restore Chinook life stages.

Unintended Effects of Model Equations
One potential unintended effect of using the EDT habitat model is to focus attention on in-stream conditions in specific reaches, since the model "views the ecosystem through the eyes of the species" (Mobrand, 1999), and does not attempt to explicitly model ecosystem processes. When reviewing the EDT diagnosis results, the Technical Committee focused on the landscape conditions and other driving factors that have created the in-stream habitat problems identified in the diagnosis. To help the Technical Committee 'hedge their bets' when reviewing the diagnosis results, the Committee including an evaluation of watershed conditions using landscape attributes such as forest cover, impervious surface, flow volume change, riparian cover, road crossings and wetlands that reflect critical landscape factors that create and maintain instream habitat conditions. This evaluation is described in detail in Appendix C-2. Additional research is needed to improve WRIA 8 understanding of the relationship between habitat attributes described in EDT and landscape level indicators. As noted in Appendix C-2, the Technical Committee intends to enhance the watershed evaluation by including indicators of riparian connectivity (rather than just percent cover by basin) and emerging information from the University of Washington Center for Water and Watershed Studies (Spirandelli 2003) about the role of land cover adjacency.

<u>4.2.3 Model Assumptions - What are critical physical and biological assumptions for the model? What biases are likely given these assumptions?</u>
A critical assumption of the EDT model is that the relative importance of reaches is determined by exposing the focal species to conditions in the reach under current and template conditions. This assumes that habitat conditions are only important during the time that a fish is exposed to them. One potential bias of this assumption is that the role of habitat-forming factors such as flow in creating and maintaining habitat conditions that support Chinook is overlooked. The Technical Committee used the Watershed Evaluation tool to identify the relative condition of key landscape process indicators and identify action recommendations intended to protect or restore these processes. The Technical Committee also evaluated coho using the EDT model, with the intent of using coho (given their greater use of and longer residence time in smaller stream systems) as a gauge of ecosystem condition. While coho results have been generated, these results have not been evaluated by the Technical Committee due to the timeline of the WRIA 8 conservation planning process. This information will be incorporated into the Conservation Strategy as part of the Adaptive Management process described in Chapter 6.

Figure 7: Relating Confidence in Key EDT Habitat Variables to Conservation Actions

From EDT chinook salmon modeling, survival is predominantly affected at these life stages:

Pre-Spawn Holding	Egg Incubation	Fry Colonization	0-Age Active Rearing

Survival at each life stage is predominantly affected by these EDT model 'Habitat Factors':

Habitat Diversity	Sediment Load	Habitat Diversity	Habitat Quantity
Habitat Quantity	Channel Stability	Flow	Habitat Diversity
		Predation	Temperature

These life-stage limiting 'Habitat Factors' are described by the following Environmental Attributes:

Habitat Factors	Environmental Attributes from EDT		
Temperature		Temperature - Max	
Flow		Hi Flow	Low Flow
Channel Stability	Wood	Bed Scour	Riparian Function
Habitat Diversity	Wood	Hydromodifications	Riparian Function
Habitat Quantity		Pool Type	Pool Area
Sediment Load		Fine Sediments	

For the affected life stages, direct survival relationships are best described for these Environmental Attributes:

Temperature - Max	Bed Scour	Pool Type/Pool Area	Fine Sediments

The Following Environmental Attributes affect survival relationships at reach and watershed scales and are Key Attributes to consider developing Actions to address:

Reach				
	Riparian Function	Hi Flow	Low Flow	Fine Sediments
	Low Flow	Hydromodifications	Hydromodifications	Hydromodifications
		Riparian Function	Riparian Function	Riparian Function
		Wood	Wood	

Watershed				
	Land Cover	Land Cover	Land Cover	Land Cover
	Groundwater Recharge/ Infiltration	Road Crossings	Wetlands	Bank Stability
		Drainage Density	Floodplain Connectivity	Road Crossings
		Stormwater Management	Water Withdrawl	Site Controls

In the Urbanizing landscape, actions that will likely be successful should,

Promote suitable habitat conditions by enhancing the benefits from:		Promote suitable habitat conditions by minimizing the impacts from:	
Watershed scale	Reach scale	Watershed scale	Reach scale
Forest Cover	Riparian Function	Impervious Area	Low Flow
Wetland Area	Wood	Road Crossings	Hydromodifications
Stormwater Management	Floodplain Connectivity	Water Withdrawl	Hi Flow
	Bank Stability	Drainage Density	Fine Sediments

In addition, EDT assumes that habitat conditions are spatially and temporally static rather than dynamic. Stochastic variation plays a critical role in a functioning ecosystem, and the dynamic nature of river and stream habitat cannot be captured through EDT without multiple model iterations that are beyond the budget and timeline of the WRIA 8 planning process. This has the potential to introduce at least four biases in the model results: (1) undervaluing the importance of extreme events (2) assuming that certain habitat attributes are equally important and can be treated independently, (3) overvaluing the importance of maintaining instream habitat conditions in a particular reach and (4) ignoring the changing effectiveness of habitat actions over time. An example of the first type of bias is the impact of aseasonal flow events or extreme low flow events on benthic communities that provide a food source for juvenile Chinook, or high flow events that deliver and sort spawning gravels. By focusing on average flow conditions, EDT may devalue the importance of flow or other processes in creating habitat conditions that support Chinook life stages. An example of the second type of bias is the potential that the habitat diversity factors (channel connectivity, large woody debris, and riparian function) can be ‘treated' independently (or additively) rather than in a coordinated, synergistic fashion to achieve the restoration potential in the reach. The third type of bias is a misguided focus on ‘locking' in-stream habitat conditions in place without considering naturally dynamic ecosystem processes. For example, protection of spawning areas by acquiring riparian areas in reaches with high spawning could be rendered ineffective if upstream gravel sources and the flows that convey spawning gravels are not maintained.

The EDT Treatment phase assumes that for a given individual action technical experts can adequately describe (1) the impact of the action on habitat attributes (2) the reaches affected by the action and (3) the time required for the effect to occur. There are uncertainties associated with each of these three factors that will need to be addressed through a rigorous monitoring and evaluation program. Temporal changes in the impact of a hypothetical conservation action are especially problematic and difficult to identify using EDT. For example, a project to setback a levee, install large woody debris, and restore riparian vegetation could result in long term improvements for the juvenile rearing life stage but short term increases in sediment, temperature, and predation that have a negative impact on juvenile Chinook. Because the Treatment phase generally looks at a longer timeframe there is a potential that the action could be considered misjudged as unsuccessful because the short-term negative impacts were not properly anticipated. WRIA 8 has not yet initiated the Treatment phase, and the results of Treatment evaluations are not expected until fall 2005.

The EDT model assumes that protection and restoration potential of a given reach is related to the exposure of each life stage to conditions in that reach. While time of exposure is not the only factor generating the reach potentials (the productivity change by life stage is also considered), the reach potential results tend to emphasize the downstream reaches that are used by a greater percentage of life history trajectories. In order to reduce the risk of a bias toward downstream reaches, the Conservation Strategy identifies priorities for protection and restoration within multiple sub-areas based on the Watershed Evaluation tool.

The model assumes that life history trajectories that are exposed to certain adverse habitat conditions will not seek to avoid those conditions. In response to stressors, actual life history trajectories may re-allocate themselves in the stream, while the model fish face decreased performance. This may produce a higher restoration potential for some reaches, and undervalue the importance of refuge areas that are actually being used by Chinook in the presence of environmental stressors. A case in point is the Sammamish River, where life history trajectories distributed evenly along stream reaches produced excess mortality in the model in response to high temperatures. In the presence of high temperatures, adult Chinook may respond by congregating at sources of cold water inflow such as stream confluences and areas of groundwater upwelling, quickly moving between cool water sources to limit their exposure to high temperatures.

4.2.4 Model Output Sensitivity - How sensitive is the model output to errors in input data? How sensitive is the model output to misspecifications of model parameters?

As part of the characterization of habitat conditions in WRIA 8, two differences in opinion arose and were evaluated using a sensitivity analysis. The first was the appropriate rating for flow attributes in the regulated Cedar River downstream of Landsburg Dam. The second was the appropriate length of Lower Rock Creek used for spawning. In both cases, the sensitivity analysis showed differences of less than 5%. This could be accurate, but it could also result from the fact that EDT is a cumulative effects model and the impact of a slight change in a key attribute is clouded by what the RSRP calls “confounding statistical noise” from multiple habitat attributes.

Additional sensitivity analyses are necessary for the key variables that drive the EDT results. These sensitivity analyses should include ranges of possible values for the most highly variable attributes such as flow. When conducting a sensitivity analysis on the EDT model, it is important to recall that the intent of the EDT model is to make relative comparisons about stream reaches and habitat attributes. The sensitivity analysis should focus less on changes to the model outputs and more on changes in the reach potentials and the relative importance of the level 3 survival attributes. Key habitat attributes to evaluate as part of the sensitivity analysis are:

- Riparian function (overbank flows, vegetation, and off-channel area)
- Large Woody Debris
- Habitat area (total area by type, and the relative proportion of each type)
- Channel connectivity (hydromodifications)
- Flows (flashiness and low flows)
- Sediment load (fine sediment and turbidity)
- Water quality (temperature, dissolved oxygen, and metals)

4.2.5 Model Verification - How have modeled predictions been field verified? Can some of the modeled outcomes be independently tested? How does the output from this model compare to that of other models, analyses, or other empirical data?

Model outputs were compared with observed population data from the WRIA 8 spawner surveys. The purpose of this comparison was to evaluate the observed versus predicted relative proportion of fish in each stream, rather than absolute abundance number for each system. Assuming a harvest impact of 30% (a Puget Sound average, and one that is probably somewhat high for WRIA 8), the abundance predictions for the Cedar River below Landsburg were the closest to observed data for all modeled streams in WRIA 8. Modeled results for the Cedar were within the range of observed values (between 133 and 975 returning adults) for the 1999-2002 period, depending on the methodology and year. The predicted relative proportion of adults returning to the North Lake Washington tributaries is generally consistent with observed data (model results for Swamp Creek and May Creek exceed observed values). The model predictions for the NLW streams were initially incorrect (overall abundance was higher than observed, and model abundance for the NLW streams was not proportional to observed values), but the problem was resolved by improving the adult Chinook trajectories in the Sammamish River to reflect studies showing that adults move quickly between cold water sources to avoid prolonged exposure to the high temperatures that exist in the Sammamish River.

As noted in the beginning of this appendix, WRIA 8 is one of the more data-rich watersheds in the Puget Sound region. This includes multiple assessments and plans for individual sub-areas and jurisdictions. As a result of the extensive studies that have been conducted in WRIA 8, it was assumed by the Technical Committee that the EDT modeling effort would not result in the identification of habitat problems that had not been previously identified. The model's chief value for WRIA 8 lie in its ability to provide an organizing framework for habitat and population data, diagnose relative priorities for habitat restoration and protection across reaches and stream systems, and evaluate the relative effectiveness of proposed conservation actions. When the EDT results are compared with pre-existing studies and plans, this assumption is largely borne out. This should not come as a surprise, as the EDT habitat characterization and trajectories are based on these same pre-existing studies and plans. For example:

- Cedar River Basin Plan and recent studies by USFWS (see Chinook workshop for citation) identify the Cedar River as rearing-limited rather than spawning-limited. This is borne out in the EDT model, where the key life stage for restoration is fry colonization. The inclusion of more accurate template life history trajectories in the EDT model would only strengthen the importance of juvenile rearing in the model results.
- Bear Creek and NLW tributaries – habitat problems associated with urbanization are consistent with previous studies and reports.
- Issaquah – channelized conditions in the lower creek, the importance of intact upstream habitat, and low flow problems in E. Fork are consistent with the Issaquah Basin Plan and subsequent studies.

Key departures between EDT results and previous analyses are as follows:

- Instream flows in the Cedar River were not diagnosed by EDT as being a moderate or severe habitat limiting factor, while the Cedar River Current and Future Conditions Report (King County, 1993) notes that altered hydrologic processes may limit the ability of habitat to support key Chinook life stages.
- Pre-spawning mortality – emerging issue that is not included in the EDT biological rules. Potential impacts of degraded water quality may be underestimated in the EDT model, particularly for the small urban streams. Several of the WRIA 8 partners are participating in work coordinated by NOAA Fisheries to understand the mechanism of pre-spawning mortality of coho and Chinook in urbanized stream systems.

4.3 WRIA 8 Work Program to Reduce Model Uncertainties

The Technical Committee has not produced a prioritized research agenda at this time – this will be the subject of Technical Committee discussions during 2005.

4.3.1 WRIA 8 Collaborative Research Needs and Priorities

Research will be conducted by WRIA 8 stakeholders jointly and individually to reduce uncertainties in WRIA 8. Whenever possible monitoring and evaluation plans should be designed to reduce uncertainties as well as evaluate the effectiveness of conservation actions. Areas of uncertainty that should be targeted by WRIA 8 stakeholders includes:

- Habitat characterization and diagnosis for the Issaquah and May Creek systems should be reviewed and, if necessary, revised.
- Current habitat characterization (see Table 1 in Section 4.2.2 for specific habitat data gaps) – riparian function and LWD are key EDT variables that are likely to impact model outputs. The Technical Committee proposes to conduct a sensitivity analysis of the 'driving' EDT habitat variables along with any other variables identified as data gaps in Table 1 to help prioritize habitat characterization research.
- Template (historic) habitat conditions – improved historic habitat information will benefit restoration project design but is not likely to significantly alter EDT outputs.
- Chinook and coho trajectories – see Section 4.3.2
- Fish – habitat relationships and species interactions in the lakes – continue to work with the University of Washington, USFWS, and others to increase our understanding of how salmon use Lake Washington and interact with other species.
- Relationships between ecosystem process, structure, and function – Sediment load is identified in several streams as a key limiting factor. While it is assumed in most cases that the source of this fine sediment is urbanization, a sediment budget and analysis of sediment transport would help to increase the certainty that restoration actions are addressing the sources of the sediment problem.
- Relationships between ecosystem process, structure, and function – Flows are identified in several streams as important for restoration, and altered hydrology was identified in the WRIA 8 Limiting Factors Report as a key habitat limiting factor. In order to increase our understanding of the importance of flow-related conservation actions, WRIA 8 stakeholders should continue to study the relationships between flow, habitat, and biological response so that this information can be incorporated into the WRIA 8 analytical framework. In addition, research is needed on groundwater recharge areas and the impacts of groundwater on stream flows and temperature.
- Evaluation of actions – the EDT model should be used to its full capability to support decision-making about conservation actions. The Treatment phase of EDT is intended to provide a relative comparison of the impacts of protection and restoration actions on Chinook and coho. This information (along with evaluations of how proposed actions impact the watershed function ratings in the Watershed Evaluation) is essential for regional prioritization of conservation actions.

4.3.2 Regional Collaborative Research Needs and Priorities

- Spawner surveys – spawner surveys throughout Puget Sound are currently conducted using a variety of methods. As part of regional recovery efforts the Technical Committee asks NOAA Fisheries to develop a standard protocol for conducting spawner surveys so that data can be compared throughout the Puget Sound ESU.
- Spawner surveys – the scope of spawner surveys should be increased to include enhanced surveys of the NLW and Cedar River tributaries.
- Trajectories – information about life history trajectories and relative juvenile survival relies on smolt traps, PIT tags, and seining that are conducted by the Army Corps of Engineers, WDFW, and other regional agencies in collaboration with the Technical Committee.

- Nearshore and estuary – additional information is needed about salmonid trajectories, habitat use of the nearshore, and current habitat conditions. Research in these areas should be coordinated with the Puget Sound Nearshore Ecosystem Restoration Program, the Puget Sound Action Team, and other Puget Sound-level efforts.
- Pre-Spawning mortality – continue to support NOAA Fisheries studies into the causal mechanism of pre-spawn mortality in coho and Chinook.
- Endocrine disrupting chemicals – support efforts to increase understanding of non-traditional water quality parameters such as pesticides and suspected endocrine disrupting chemicals.
- Global warming –continue to monitor UW and other investigations into the impacts of climate change.

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Appendix C-4

WRIA 8 EDT Customization:

Derivation of EDT Rules and Habitat Information for Large Lakes, Hiram M. Chittenden Locks, and Estuarine/Nearshore Marine Areas

Prepared by Mobrand Biometrics

For the WRIA 8 Technical Committee

December, 2003

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INTRODUCTION

The EDT model, from which the WRIA 8 Habitat Assessment Model derives, is a habitat model—where habitat conditions (ecological attributes) are translated into population survival expectations for salmon species. Two major steps needed to be completed before model analysis of Chinook and coho in WRIA 8 could begin: (a) describe the ecosystems in terms of the ecological attributes that form the input to the EDT model, and (b) develop translation rules for the unique environments present in WRIA 8, namely Lake Washington and Lake Sammamish.

This work was coordinated through the Technical Committee and involved several experts in addition to the MBI consultant team. In this section we describe the rules for converting habitat attributes for the lake environment into survival parameters for the model.

A team of experts worked on the development of habitat-survival relationships for the environments that are unique to WRIA 8—namely Lake Washington, Lake Sammamish, the Lake Washington Ship Canal, the Crittenden Locks, and the estuary and near-shore marine areas. We refer to these relationships as translation rules or simply "rules." These rules tell the model how to convert habitat inputs into survival values for chinook and coho salmon. The following steps were followed:

1. A "lakes and ship-canal" team was formed of individuals with particular expertise in the ecology of the lakes and ship canal.
2. The team convened a two-day workshop to share information and knowledge about ecological characteristics of the lake environment as they might affect salmonids.
3. A smaller work group held further workshops to refine the particular set of attributes that would be used to characterize the lake and ship canal ecosystem.
4. The group then created a procedure for developing draft translation rules using the new lake attributes. First, a set of hypothetical scenarios was developed, expressed in terms of lake attributes. Then, team members were asked to independently rate these scenarios with respect to the survival of Chinook and coho juveniles.
5. MBI developed a set of tools to conduct the survival rating exercise. The experts completed the ratings independently.
6. MBI synthesized the expert ratings and converted the results into a set of lake rules, which were implemented in the model.
7. The team, with assistance from members of the Technical Committee (and King County staff), next divided the lake and ship canal environments into ecologically homogeneous segments and characterized each segment (month by month) in terms of the model input attributes, including the new lake attributes.

8. Concurrent with the development of lake rules, a different team held two workshops to discuss aspects of the locks and the estuary and nearshore marine areas as they affect salmon survival. A set of survival values was developed by the individuals most familiar with the locks. For the estuary and marine areas, the Tidal Habitat Model (THM) developed by PenTec was used as the basis for developing model rules and attributes for these environments.

LAKES (WASHINGTON, SAMMAMISH, AND SHIP CANAL)

An early conclusion by the lakes team was that the predominant cause of mortality for juvenile salmon in the lakes is predation. It was also clear that both abundance of predators and the vulnerability of the prey are affected by factors such as bank type, substrate, and predator species composition.

Working with the lakes experts, we defined attributes specific to the lake environment to capture population status of important predator species and environmental attributes that modify predation effects (Table C-1). Most attributes were characterized using ratings on a scale of 0 to 4, spanning a range of possible conditions. Habitat composition attributes (bank type and percent inner and outer littoral) were characterized as a percent of littoral reach. Generally, there is a consistent direction to the attribute ratings, where lower values correspond with more pristine environmental conditions and higher values with more “managed” conditions. This pattern differs for predator status attributes. For these attributes, 0 to 4 ratings represent abundance of species, where 0 or low values represent lower abundance of that species. The system also allowed the experts to indicate the precision of their ratings. Table C-2 summarizes the attribute rating definitions for the lakes.

The opinions of the lakes experts was captured by constructing a series of hypothetical scenarios, each of which described a littoral or limnetic lake segment in terms of a predefined set of attribute ratings. The experts then independently rated the survival conditions for the focal species for each scenario. The results of this exercise are shown in Figure C-1. Two general viewpoints emerged: those who saw a relatively weak relationship between habitat attributes and predator effect (lower charts), and those who saw a stronger relationship. There is, however, a relatively good agreement on the direction of the effect as shown in the lower charts. We elected to model the more habitat sensitive viewpoint represented by the upper charts of Figure C-1.

Bank type and predator species composition emerged during the rule building process as the most critical factors affecting survival of juvenile salmon in the lakes environment. A computational framework was constructed around a set of sensitivity curves as illustrated in Figure C-2 and C-3. The sensitivity curves are shown in figures C-4 through C-44.

The rules have been coded and incorporated in the EDT model along with the lake specific habitat attributes.

HIRAM M. CHITTENDEN LOCKS

A workshop was convened in December 2002 with a larger group to review information relevant to the Locks. General concepts and key data sources were discussed at this workshop. Following the workshop Fred Goetz (U.S. Army Corps of Engineers) and Bob Pfeiffer (consultant for City of Seattle) were identified as key people who had information, or were knowledgeable about, the locks and would provide expert opinion when information was missing. Their inputs were the basis for developing survival rules at the Locks.

A total of five major routes where identified for juvenile chinook and coho seaward migration through the Locks (Figure C-45). There are two possible routes through the large and small locks, either through the culvert intakes or through the miter gates (i.e., the lock itself). The saltwater drain can either route directly below the Locks ("Old" saltwater drain) or be routed into the fish ladder (Aux Fish supply). Altogether, eight potential routes were identified at the Locks.

We asked the experts to provide information about conditions from March through the end of August to ensure that we had all of the time periods captured in the model. The Habitat Assessment model includes a life history model that routes Chinook and coho past the Locks during the appropriate time periods (see Figure C-46).

The first step in modeling survival at the Locks was to determine juvenile survival by route. Survival for most routes exceeded 90 percent (Table C-3). The exception was the saltwater drain to the fish ladder. Survival for this route is 0 because of a screen at the outlet of the pipe.

Once survival assumptions were determined, the next step was to perform an assessment of the percent of the juvenile migration utilizing each route, by week. A weekly time step was chosen because of the rapid change in Lock operations that can occur mid month (typically June – July). In addition, because Lock operations change from year to year based on water availability, we characterized three scenarios for fish passage: 1) low water year, 2) normal water year, and 3) high water year (Tables C-4, C-5, and C-6). What distinguishes these scenarios from one another is how far into the summer the spillway flumes can operate. In a normal water year, the flumes were assumed to operate at maximum efficiency until the second week of June and at reduced efficiency until late June. During a high flow year the maximum efficiency period was extended until the end of June and the reduced efficiency until mid-July. And, finally, in a low water year, the flumes were shut off completely by mid June. All results from the Habitat Assessment model are based on the normal water year condition.

Total survival for a week was calculated as the percent of fish using each route multiplied by the route survival and summed across all routes. Note that although the salt water drain to the fish ladder has 0 survival, this route has minimal effect on overall survival because few fish are entrained in this route.

Data Uncertainty

Data uncertainty was captured for both survival by route and percent fish using each route. The experts were asked to rate data uncertainty on a scale from 1 to 4 (Table C-7). Data uncertainty tended to be high for both types of assumptions. Table C-8 summarize the range of uncertainty reported by the experts for both survival and fish migration route. Note that in both cases, uncertainty increases later in the season.

ESTUARINE/NEARSHORE RULES

A workshop was convened in early January of 2003 to review possible approaches to characterizing the estuarine and nearshore reaches for the Habitat Assessment model. At this workshop, we presented the idea of using the Tidal Habitat Model (THM) developed by PenTec Environmental to characterize these areas. MBI had already developed a provisional set of estuarine and nearshore survival data based on earlier work done on a Puget-Sound-wide EDT analysis for the Washington Department of Fish and Wildlife. We hired PenTec to summarize existing THM assessments and to complete a THM assessment for missing areas in WRIA 8. The THM scores were fed into our existing data framework for estuarine and nearshore survival assumptions.

THM is a quick method of inventorying estuarine and nearshore habitat using aerial photos and a single visit during low tide. Using the Tidal Habitat Model protocols, discrete units of habitat were delineated based on physical changes in shoreline/nearshore habitat types. These habitat units are termed assessment units (AUs). AUs are nested within larger geographic units called Ecological Management Units (EMUs). These larger units were the geographic units applied in the WRIA 8 Habitat model for nearshore areas. The overall EMU score was calculated by taking the length-weighted average of the AUs.

The THM asks a series of thirty-four "yes" or "no" questions about the hydrological, chemical, physical, geomorphologic, biological, and landscape features (indicators) present within the AU (Table C-9). Three questions were removed from the assessment because they addressed long-term process features of the AU. We were interested only in a characterization that represented conditions as currently experienced by juvenile salmonids or that were thought to exist in the template. The THM was modified to include a new question (Question 35) to address the fact that the Ship Canal and Lake Washington provide a source of Daphnia to the AU just seaward of the locks (AU 11.03, 11.04, 11.05, and 11.06). It was suggested that this be added as a habitat feature that greatly increases the value of this area for juvenile salmonids. This question was given a multiplier of 2 - i.e., 2 times the raw THM score.

The model is focused only on indicators that are of direct relevance to anadromous salmonids, primarily juveniles. Values are based on the degree to which each indicator is judged to be associated with the positive aspects of each function: indicators strongly associated with the function being assessed are assigned a value of 3; those moderately associated are assigned a value of 2; those weakly associated with the function are assigned a value of 1 (Table C-9). Several questions include multiple sub-questions with only one sub-question to be answered under each question. Aspects of some indicators have been judged by the THM developers to be disproportionately beneficial (e.g., presence of a natural tidal channel wetted at mean lower low water (MLLW)) or adverse (e.g., presence of riprap or bulkheads below mean higher high water (MHHW)) to such a degree that they are assigned positive or negative multipliers that are applied to the sum of the values from all the other indicators. Different multipliers for 0-age juvenile chinook salmon and 1-age juvenile coho salmon for certain indicators reflect differences in habitat reference/requirements for these species. A discussion of the underlying rationale and assumptions for each question is available from PenTec.

Characterization

Starting from the north, EMU 8, from Mukilteo to Picnic Point, was completed for the City of Mukilteo (December, 2000) using the Ecology shoreline oblique photos (1993 version), topographic maps, and a passing familiarity with the nature of the shorelines involved. Lacking any better eelgrass data, we arbitrarily assigned a positive response to question 23b (eelgrass present over 10 to 25 percent of the length of the AU) to all AU.

EMU 9 (Picnic Point to Edwards Point) was scored independently for the City of Edmonds (summer 2001) using ecology photos, topographic maps, frequent shore visits, and a shoreline survey from a skiff during low tide. Greater specificity was available to score the eelgrass (Question 23) from the skiff survey, but there were still no real eelgrass survey data available (pre-ShoreZone, Sound Transit, and MOSS).

EMU 10 through EMU 12 (Edwards Point to West Point) were scored based on aerial photos, topographic maps, past familiarity, and a site walk from Edwards Point to Point Wells in January this year. MOSS web eelgrass maps were used to answer Question 23.

For the template condition ("as good as it can get") the shoreline of each EMU was assigned a mix of the "pristine" habitats that matched our expectations of what the shoreline would look like absent all development. Thus, for example, we looked at each AU and decided which of the 5 pristine shoreline habitat types would be present in the absence of development. Thus, comparison of the existing versus the Template condition can be used as an indicator of how good the habitat quality is today relative to what it might have been in1850. For the purposes of assuming the template conditions for the Ship Canal, we assumed that an essentially estuarine channel would exist from the base of the presumed cascades (our Template condition for the Locks) to the outer estuary boundary. We assumed daphnia were present in the template.

Results

Average THM scores for each EMU are presented in Table C-10 for nearshore units. THM scores represent the weighted averages for all nearshore AUs in the EMU. Estuarine units typically were a single AU (Table C-11). In the case of the Lake Washington estuary, we calculated the unweighted average across all AUs.

THM scores were converted to relative survival assumptions based on an assumption about the distribution of the THM score for each juvenile life stage, a minimum relative survival for the lowest scores (based on previous EDT modeling in Puget Sound streams). They were interpolated between all intermediate scores with a relative survival of 1.0 for THM scores greater than 85 for estuarine units and greater than 50 for nearshore units (Table C-12). THM scores are not applicable to the adult life stage. Conclusions for adult relative survival in nearshore and estuarine reaches were based on earlier work completed on a Puget-Sound-wide EDT analysis for the WDFW.

Size of estuarine and nearshore units were calculated from topographic maps and field visits (Table C-13). The area of nearshore units was assumed to extend outwards 500 m from the shoreline. Length of the units was determined from USGS topographical maps.

Table C-1. Level 2 lake environmental attribute definitions - Version 2 (December 18 update).

Attribute class	Attribute	Attribute Definition
Depth zone	Inner littoral - shallows	The percentage of the water surface area within the geographic unit consisting of shallows, defined as areas with depths <=1 m.
	Outer littoral	The percentage of the water surface area within the geographic unit consisting of depths generally associated with the outer littoral area, defined here as areas with depths >1 m and <=12 m.
Shoreline features	Bank type - Beach	The percentage of shoreline comprised of largely featureless beach (generally exposed to some wave action).
	Bank type - Soft bank - protected	The percentage of shoreline comprised of natural soft bank, which is generally in an area provided some type of protection from wave action.
	Bank type - Hardened with interstices (e.g., rip rap)	The percentage of shoreline comprised of hardened bank composed of material containing interstitial voids. Bank hardening under these conditions will be due to natural processes such as boulder slides or scree or due to human placement such as riprap. Such banks will generally be sloped.
	Bank type - Hardened without interstices (e.g., bulkhead)	The percentage of shoreline comprised of hardened bank composed of material containing little or no interstitial voids. Bank hardening under these conditions will be due to natural outcrops or cliffs (comprised of rock or cemented till), or due to human placement of bulkheads. Such banks will generally have vertical (or nearly so) faces.
	Bottom slope	The slope of the lake bottom for a discrete area of shoreline from the shoreline to a depth of 1 m. Note: the slope from the shoreline out to the 5 m depth will generally be assumed to be comparable to the slope to 1 m depth.
	Daily lake fluctuation	The average amount of diel fluctuation in lake level, measured as change in lake surface level. This condition is the result of hydroelectric operations.
	Inlet stream deltas	The relative abundance of perenial tributaries to the lake within the geographic unit, expressed as the number of tributaries per mile of shoreline.
	In-water LWD	The relative amount of natural wood (both small and large) within the reach. Dimensions of what constitutes LWD are defined as pieces >0.1 m diameter and >2 m in length. Small wood would include aggregates of smaller pieces.
	In-water man-made structures	The abundance of anthropogenic structures which produce shade such as docks, walkways, piers, and boats.
	Substrate type - Silt	The percentage of the lake bottom substrate within the littoral zone comprised of largely of silt (particle sizes < 1mm).
	Substrate type - Sand	The percentage of the lake bottom substrate within the littoral zone comprised of largely of sand (particle sizes > 1 mm and < 6 mm).
	Substrate type - Gravel	The percentage of the lake bottom substrate within the littoral zone comprised of largely of gravel (particle sizes > 6 mm and < 60 mm).

Attribute class	Attribute	Attribute Definition
	Substrate type - Mixed coarse	The percentage of the lake bottom substrate within the littoral zone comprised of largely of mixed coarse material (particle sizes > 60).
Water quality	Dissolved oxygen	A measure of the average dissolved oxygen within the water column for the specified time interval. (measured at 12 m, 12 m, 10 m, and 2 m depths in Lake Washington, Lake Sammamish, the Ship Canal, and the Sammamish Slough.
	Temperature - Maximum	Maximum water temperatures within the geogrphic unit during a month (measured at 12 m, 12 m, 10 m, and 2 m depths in Lake Washington, Lake Sammamish, the Ship Canal, and the Sammamish Slough). (Note: depths agreed to by technical group on December 4-5, 2002).
	Temperature - Minimum	Minimum water temperatures within the geogrphic unit during a month (measured at 12 m, 12 m, 10 m, and 2 m depths in Lake Washington, Lake Sammamish, the Ship Canal, and the Sammamish Slough). (Note: depths agreed to by technical group on December 4-5, 2002).
	Temperature - Spatial variation	Spatial variation of temperature within the geographic unit, either due to stream inlets, groundwater seeps, or depth within the geographic unit.
	Metals - Water column	The extent of dissolved heavy metals within the water column.
	Metals/toxicants - Sediments	The extent of heavy metals and miscellaneous toxic pollutants within the lake bottom sediments.
	Toxicants - Misc	The extent of miscellaneous toxic pollantants (other than heavy metals) within the water column.
	Turbidity	A measure of turbidity within the geographic area of interest in the lake, expressed in nephelometric turbidity units (NTU). Turbidity is an optical property of water where suspended fine particles such as clays and colloids, and some dissolved materials cause light to be scattered.
Biological community	Benthos	The relative abundance of chironomidae during spring months. Ranges of chironomid densities to be based on data in Michele Koehler's research results -- to be provided by Beauchamp.
	Fish pathogens	The presence of pathogenic organisms (relative abundance and species present) having potential for affecting survival of salmonid fishes.
	Lakeshore vegetation	The relative amount of overhanging vegetation, including trees, growing along the shoreline.
	Macrophytes	The relative amount and density of rooted submerged and floating aquatic vegetation in the lake's littoral zone.
	Neuston	A measure of the organisms existing on the surface film of water in a lake.

Attribute class	Attribute	Attribute Definition
	Predation risk - fish species	Level of predation risk on focal species due to the presence and relative abundance of specific predatory fish species within the lake (species or groups considered include sculpin, cutthroat trout, crayfish, pikeminnow, hatchery yearling sized coho or chinook, residual coho or chinook, bass (smallmouth and largemouth grouped), yellow perch, and brown bullhead) Note: this measure applied for each species or group.
	Predation risk - bird species	Level of predation risk on focal species due to the presence and relative abundance of specific predatory bird species associated with the lake (species or groups considered include grebes, mergansers, cormorants, herons, and gulls). Note: this measure applied for each species or group.
	Prey alternatives for key predators	Relative abundance or diversity of prey species that can provide alternative food sources, other than the focal salmonid species, to the key predator species (identified under Predation Risk). An example of a alternative food source in Lake Washington is longfin smelt.
	Zooplankton	The density of Daphnia.

Table C-2. Level 2 lake environmental attributes and associated rating definitions.

Attribute class	Attribute	Index Value 0 Definition	Index Value 1 Definition	Index Value 2 Definition	Index Value 3 Definition	Index Value 4 Definition
Depth zone	Inner littoral - shallows	Entered as a percent of littoral reach				
	Outer littoral	Entered as a percent of littoral reach				
Shoreline features	Bank type - Beach	Entered as a percent of littoral reach				
	Bank type - Soft bank - protected	Entered as a percent of littoral reach				
	Bank type - Hardened with interstices (e.g., rip rap)	Entered as a percent of littoral reach				
	Bank type - Hardened without interstices (e.g., bulkhead)	Entered as a percent of littoral reach				
	Bottom slope	Average slope of lake bottom within the geographic unit is <3%.	Average slope of lake bottom within the geographic unit is >=3% and <6%.	Average slope of lake bottom within the geographic unit is >=6% and <9%.	Average slope of lake bottom within the geographic unit is >=9% and <12%.	Average slope of lake bottom within the geographic unit is >=12%.
	Daily lake fluctuation	Diel fluctuation is minimal, lake is not regulated.	Diel fluctuation >0 m and <=0.3 m.	Diel fluctuation >.3 m and <=1 m.	Diel fluctuation >1 and <= 2 m.	Diel fluctuation >2 and <10 m.
	Inlet stream deltas	>1.5 tributaries per mile of shoreline	>0.9 and <=1.5 tributaries per mile of shoreline	>0.3 and <=0.9 tributaries per mile of shoreline	>0 and <=0.3 tributaries per mile of shoreline	No tributaties present

Attribute class	Attribute	Index Value 0 Definition	Index Value 1 Definition	Index Value 2 Definition	Index Value 3 Definition	Index Value 4 Definition
	In-water LWD	Complex mixtures of wood present, consisting of a diversity of sizes, decay classes, and species, occurring in frequent clumps or massive jams along the shoreline.	Complex mixtures of wood present, consisting of a diversity of sizes, decay classes, and species, scattered at infrequent locations along the shoreline; representive of a situation where some management is occurring to reduce frequency compared to index level 0, or where the pristine environment consists of a mixture of forest and rangeland.	Scattered clumps of aggregates of small wood and scattered pieces of large wood of old decay classes (therefore missing branches); or aggregates of small wood rare but accumulations of logs associated with log dumps and rafting.	Aggregates of complex small wood (consisting of branches) rare and few, isolated pieces of large wood not associated with smaller pieces.	Aggregates of small wood and LWD very rare or not present.
	In-water man-made structures	No structures along shoreline or structure are rare, i.e. <= 2 structures per mile.	Low density of structures along shoreline, > 2 and <= 10 structures per mile.	Moderate density of structures along shoreline, > 10 and <= 30 structures per mile.	High density of structures along shoreline, > 30 and <= 75 structures per mile.	Extremely high density of structures along shoreline, exceeding 75 structures per mile, or shoreline encompasses a boat marina (value 4).
	Substrate type - Silt	0% to 20% of area	20% to 40% of area	40% to 60% of area	60% to 80% of area	80% to 100% of area
	Substrate type - Sand	0% to 20% of area	20% to 40% of area	40% to 60% of area	60% to 80% of area	80% to 100% of area

Attribute class	Attribute	Index Value 0 Definition	Index Value 1 Definition	Index Value 2 Definition	Index Value 3 Definition	Index Value 4 Definition
	Substrate type - Gravel	0% to 20% of area	20% to 40% of area	40% to 60% of area	60% to 80% of area	80% to 100% of area
	Substrate type - Mixed coarse	0% to 20% of area	20% to 40% of area	40% to 60% of area	60% to 80% of area	80% to 100% of area
Water quality	Dissolved oxygen	> 8 mg/L (allows for all biological functions for salmonids without impairment at temperatures ranging from 0-25 C)	> 6 mg/L and < 8 mg/L (causes initial stress symptoms for some salmonids at temperatures ranging from 0-25 C)	> 4 and < 6 mg/L (stress increased, biological function impaired)	> 3 and < 4 mg/L (growth, food conversion efficiency, swimming performance adversely affected)	< 3 mg/L
	Temperature - Maximum	Warmest day < 10 C	Warmest day>10 C and <16 C	> 1 d with warmest day 22-25 C or 1-12 d with >16 C	> 1 d with warmest day 25-27.5 C or > 4 d (non-consecutive) with warmest day 22-25 C or >12 d with >16 C	> 1 d with warmest day 27.5 C or 3 d (consecutive) >25 C or >24 d with >21 C
	Temperature - Minimum	Coldest day >4 C	< 7 d with <4 C and minimum >1 C	1 to 7 d < 1 C	8 to 15 days < 1 C	> 15 winter days < 1 C
	Temperature - Spatial variation	Numerous sources of temperature variation due to inlets, seeps, or depth, well distributed within the geographic unit.	Many sources of temperature variation due to inlets, seeps, or depth, but not well distributed within the geographic unit.	Intermittent sources of temperature variation due to inlets, seeps, or depth, and not evenly distributed.	Infrequent sources of temperature variation due to inlets, seeps, or depth, and not evenly distributed.	Very little or no evidence of variation due to stream inlets, seeps or depth.

Attribute class	Attribute	Index Value 0 Definition	Index Value 1 Definition	Index Value 2 Definition	Index Value 3 Definition	Index Value 4 Definition
	Metals - Water column	No toxicity expected due to dissolved heavy metals to salmonids under prolonged exposure (1 month exposure assumed).	May exert some low level chronic toxicity to salmonids (1 month exposure assumed).	Consistently chronic toxicity expected to salmonids(1 month exposure assumed).	Usually acutely toxic to salmonids (1 month exposure assumed).	Always acutely toxic to salmonids (1 month exposure assumed).
	Metals/toxicants - Sediments	Metals/pollutants at natural (background) levels with no or negligible effects on benthic dwelling organisms (under continual exposure).	Deposition of metals/pollutants in low concentrations such that some stress symptoms occur to benthic dwelling organisms (under continual exposure).	Stress symptoms increased or biological functions moderately impaired to benthic dwelling organisms; area occupied only by tolerant species.	Growth, food conversion, reproduction, or mobility of benthic organisms severely affected; area occupied only by metals/pollutant-tolerant species.	Metals/pollutants concentrations in sediments are lethal to large numbers of the benthic species.
	Toxicants - Misc	No substances present that may periodically be at or near chronic toxicity levels to salmonids.	One substance present that may only periodically rise to near chronic toxicity levels (may exert some chronic toxicity) to salmonids.	More than one substance present that may periodically rise to near chronic toxicity levels or one substance present > chronic threshold and < acute threshold (consistently chronic toxicity) to salmonids.	One or more substances present > acute toxicity threshold but < 3X acute toxicity threshold (usually acutely toxic) to salmonids.	One or more substances present with > 3X acute toxicity (always acutely toxic) to salmonids.
	Turbidity	<0.5 NTUs	>= 0.5 and <1.5 NTUs	>= 1.5 and <3 NTUs	>= 3 and <7 NTUs	>= 7 NTUs

Attribute class	Attribute	Index Value 0 Definition	Index Value 1 Definition	Index Value 2 Definition	Index Value 3 Definition	Index Value 4 Definition
Biological community	Benthos	Density of dipterans (especially chironomids) is very high, > __ organisms per square m; this density would provide maximum ration to young salmonids under suitable temperatures producing high growth rates.	Density of dipterans (especially chironomids) is high, > __ and < __ organisms per square m; this density would produce slightly reduced growth to young salmonids under suitable temperatures compared to that produced under maximum ration.	Density of dipterans (especially chironomids) is moderate, > __ and < __ organisms per square m; this density would provide a moderate ration to young salmonids under suitable temperatures producing positive, though significantly reduced growth than would occur with maximum ration.	Density of dipterans (especially chironomids) is low, > __ and < __ organisms per square m; this density would result in no net increase in weight for young salmonids under suitable temperatures.	Density of dipterans (especially chironomids) is very low, < __ organisms per square m; this density would result in weight loss for young salmonids under suitable temperatures.
	Fish pathogens	No historic or recent fish stocking in drainage and no known incidences of whirling disease, C. shasta, IHN, or IPN	Historic fish stocking, but no fish stocking records within the past decade, or sockeye population currently existing in drainage, or known incidents of viruses among kokanee populations within the watershed.	On-going periodic, frequent, or annual fish stocking in drainage or known viral incidents within sockeye, chinook, or steelhead populations in the watershed.	Operating hatchery within the reach or in the reach immediately downstream or upstream	Known presence of whirling disease or C. shasta within the watershed.

Attribute class	Attribute	Index Value 0 Definition	Index Value 1 Definition	Index Value 2 Definition	Index Value 3 Definition	Index Value 4 Definition
	Lakeshore vegetation	Trees grow along >80% of the shoreline.	Trees grow along >50% and <=80% of the shoreline.	Trees grow along >20% and <=50% of the shoreline.	Trees grow along >20% and <=10% of the shoreline.	Trees grow along >=0% and 10% of the shoreline (value 4 is 0%).
	Macrophytes	No rooted vegetation in the lake's littoral zone	0-25% of the lake's littoral zone is occupied by rooted vegetation at densities between 0% and 50%	25-50% of the lake's littoral zone is occupied by rooted vegetation at densities between 25% and 75%	50-75% of the lake's littoral zone is occupied by rooted vegetation at densitiesbetween 50% and 75%	75-100% of the lake's littoral zone is occupied by rooted vegetation at densities > 75%
	Neuston	>50% of lake surface has neuston present	>25 and <50% of lake surface has neuston present	>10 and <25% of lake surface has neuston present	>1 and <10% of lake surface has neuston present	<1% of lake surface has neuston present

Attribute class	Attribute	Index Value 0 Definition	Index Value 1 Definition	Index Value 2 Definition	Index Value 3 Definition	Index Value 4 Definition
	Predation risk - fish species	Predatory species of concern not present.	Population of predatory species at very low density, reflecting a population of marginal sustainability. All sizes classes of concern at low density.	Population of predatory species stable, though depressed compared to a healthy, robust population due to reduced environmental quality, moderate to severe harvest pressure, or strong competitive interactions with other species.	Population of predatory species considered healthy with all age and size classes of concern present, though abundance reduced from maximum potential capacity due to one or more of the following: harvest, bottlenecks on habitat capacity at younger age classes, or competition with one or more competing species. Note: this is the status that is assumed if the species were naturally occurring within a diverse assemblage of species.	Population of predatory species very robust and abundant, densities of all age and size classes of concern present and at high levels. This status level corresponds to an especially high abundance due to factors that favor this species in the Lake Washington system due to one or more of the following: low harvest impact, favorable habitat conditions, or low competition interactions with other potentially competing species.

Attribute class	Attribute	Index Value 0 Definition	Index Value 1 Definition	Index Value 2 Definition	Index Value 3 Definition	Index Value 4 Definition
	Predation risk - bird species	Predatory species of concern not present.	Population of predatory species at very low density, reflecting a population of marginal sustainability.	Density of species corresponds to a stable, though depressed level compared to the healthy average level associated with pristine condition due to watershed development.	Density of species corresponds to a healthy population for the species under average conditions that might have prevailed prior to watershed development.	Extremly high densities of the species present due to unusually favorable conditions or proximity to reproductive areas.
	Prey alternatives for key predators	Relative abundance or diversity of alternative food sources very high providing significant opportunities for key predators to switch from focal species.	Intermediate condition where likelihood for switching to alternative prey is relatively high but still less than would be provided under maximum abundance or diversity of alternative prey items.	Relative abundance or diversity of alternative food sources moderate providing a well balanced opportunity for key predators to target other species besides the focal species.	Intermediate condition where likelihood for switching to alternative prey is relatively low but still providing some ameliorating effect away from focal species.	Relative abundance or diversity of alternative food sources for key predators is very low, providing virtually no opportunity for switching from focal species.

Attribute class	Attribute	Index Value 0 Definition	Index Value 1 Definition	Index Value 2 Definition	Index Value 3 Definition	Index Value 4 Definition
	Zooplankton	Density of Daphnia is very high, > 15 daphnia per liter. This density would provide maximum ration to young salmonids under suitable temperatures producing high growth rates.	Density of Daphnia is high, >5 and 15< daphnia per liter. This density would produce slightly reduced growth to young salmonids under suitable temperatures compared to that produced under maximum ration.	Density of Daphnia is moderate, >1 and 5< organisms per liter. This density would provide a moderate ration to young salmonids under suitable temperatures producing positive, though significantly reduced growth than would occur with maximum ration.	Density of Daphnia is low, < 1 daphnia per liter and <10 adult copepods per liter. This density would result in no net increase in weight for young salmonids under suitable temperatures.	Density of Daphnia is very low, 0 daphnia per liter and <5 adult copepods per liter. This density would result in weight loss for young salmonids under suitable temperatures.

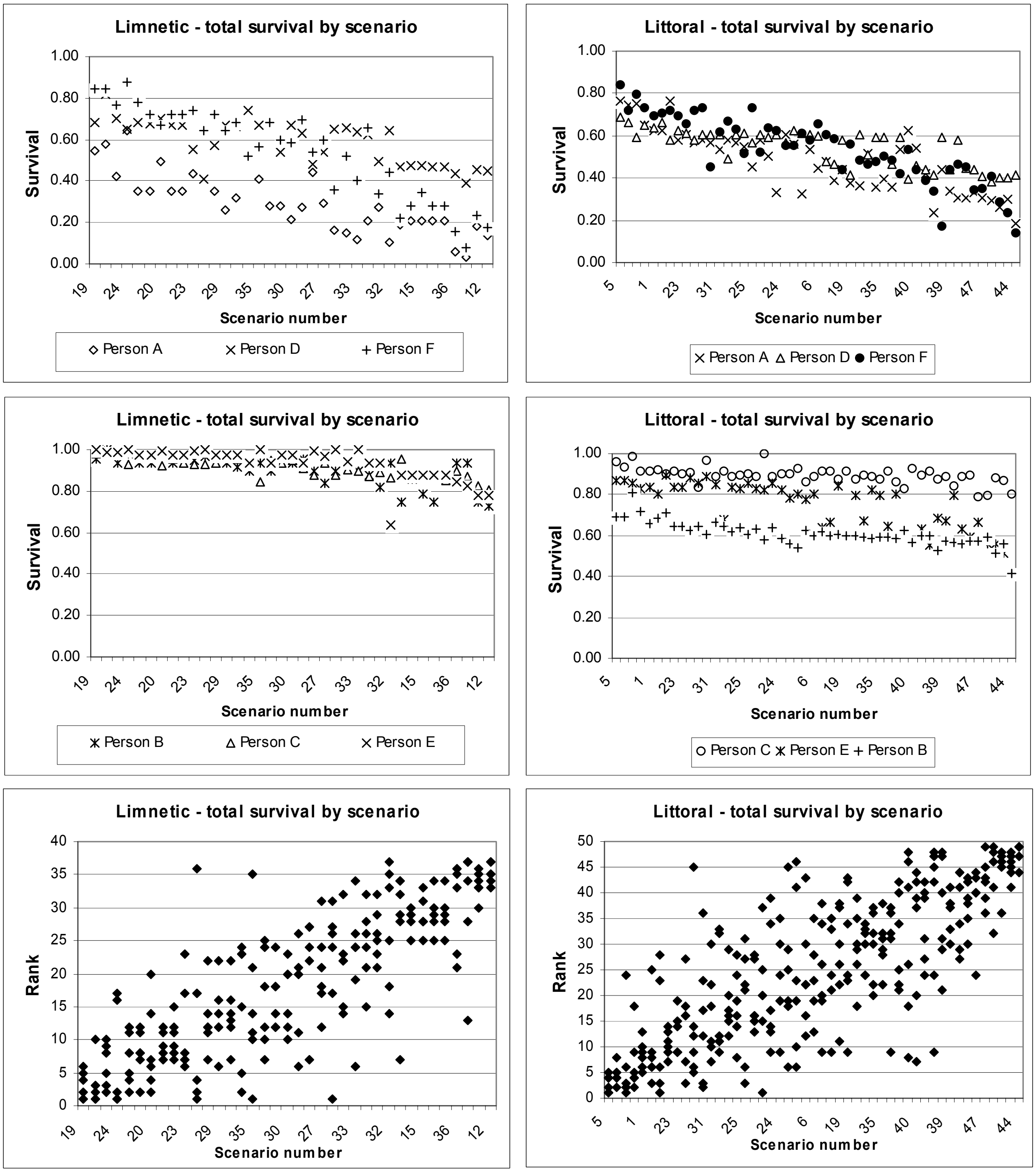


Figure C-1. Results of expert panels' rating of lake habitat scenarios.

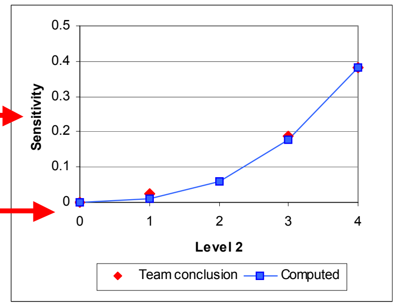
RULE STRUCTURE AND FORMULATION

Base survival conclusions for scenarios (littoral)

Person	Average		
Bank type	Beach		
Substrate type	Sand		
Species	Cutthroat		
Status (Level 2)	1	3	4

	Scenario		
Attribute	5	3	4
BT-Beach	1	1	1
BT-HardSloped	0	0	0
BT-HardVert	0	0	0
BT-Soft	0	0	0
ST-Gravel	0	0	0
ST-Coarse	0	0	0
ST-Sand	1	1	1
ST-Silt	0	0	0
Benthos	1	1	1
Slope	0	0	0
DielLevel	0	0	0
Deltas	4	4	4
LWD	4	4	4
ManStructures	0	0	0
ShoreVeg	0	0	0
Macro	0	0	0
Neuston	1	1	1
PreyAlts	2	2	2
SeasLevel	1	1	1
TempMax	1	1	1
Turb	0	0	0
Zooplank	1	1	1
Survival	**0.98**	**0.82**	**0.63**

Base mortality rate curve for reference conditions



Sensitivity

Curve fitted

Sensitivity = F x Level2^{Z}

Parameters estimated

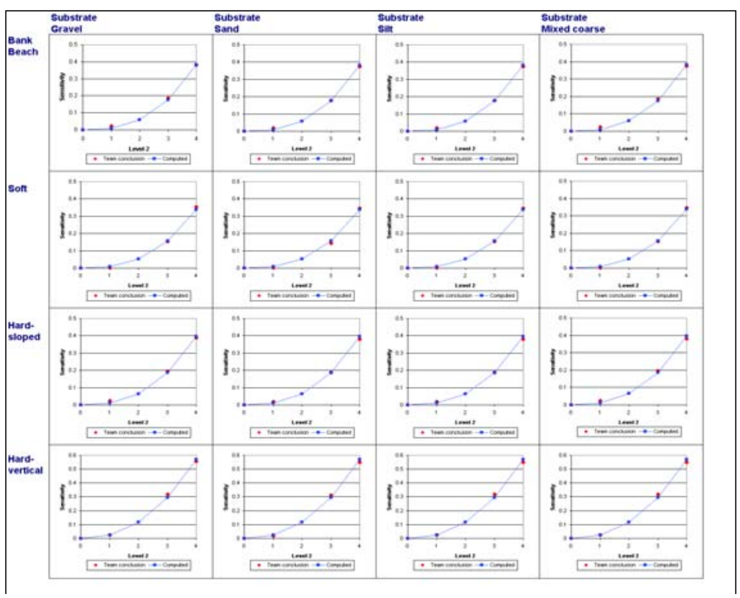


Figure C-2. The first step in the construction of predation rules for the lake environment.

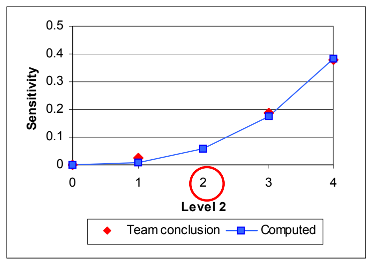
Derivation of modifying effects of other attributes

Survival conclusions for scenarios with modifiers

Person	Average	
Bank type	Beach	
Substrate type	Sand	
Species	Cutthroat	
Status (Level 2)	2	2

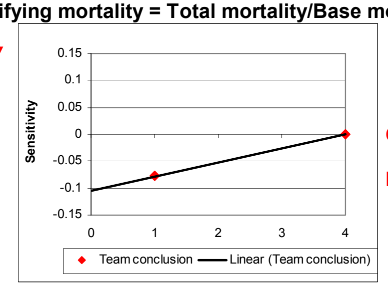
Attribute	Scenario 26	Scenario 23
BT-Beach	1	1
BT-HardSloped	0	0
BT-HardVert	0	0
BT-Soft	0	0
ST-Gravel	1	1
ST-Coarse	0	0
ST-Sand	0	0
ST-Silt	0	0
Benthos	1	1
Slope	0	0
DielLevel	0	0
Deltas	4	4
LWD	1	4
ManStructures	0	0
ShoreVeg	0	0
Macro	0	0
Neuston	1	1
PreyAlts	2	2
SeasLevel	1	1
TempMax	1	1
Turb	0	0
Zooplank	1	1
Total survival (with modifying effect)	**0.98**	**0.82**

Base mortality rate



At Status of rating 2

Modifying mortality = Total mortality/Base mortality



Curve fitted

Parameters estimated

Quotient residual mortality rates derived for all modifying attributes

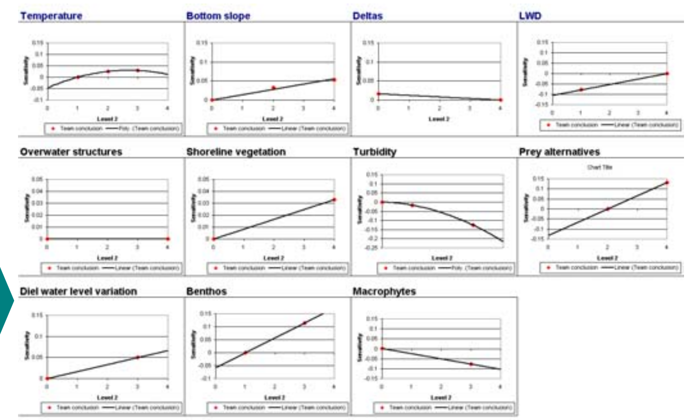


Figure C-3. The second step in the construction of predation rules for the lake environment.

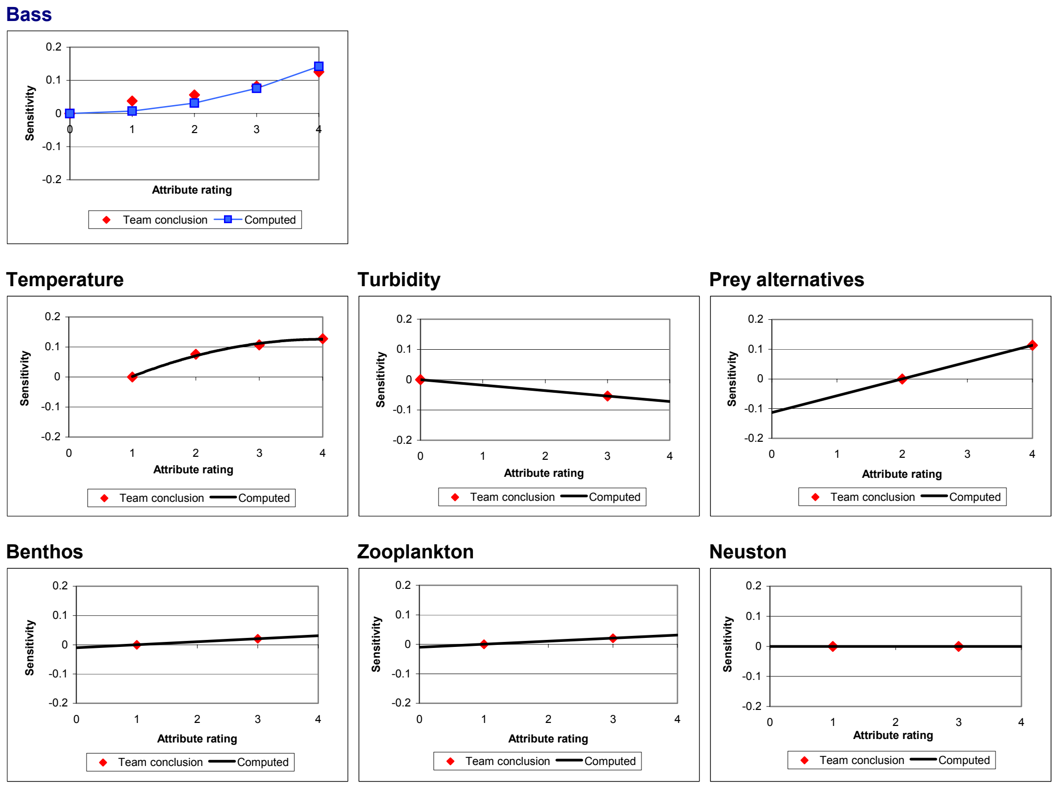


Figure C-4. Sensitivity curves for Bass in limnetic areas.

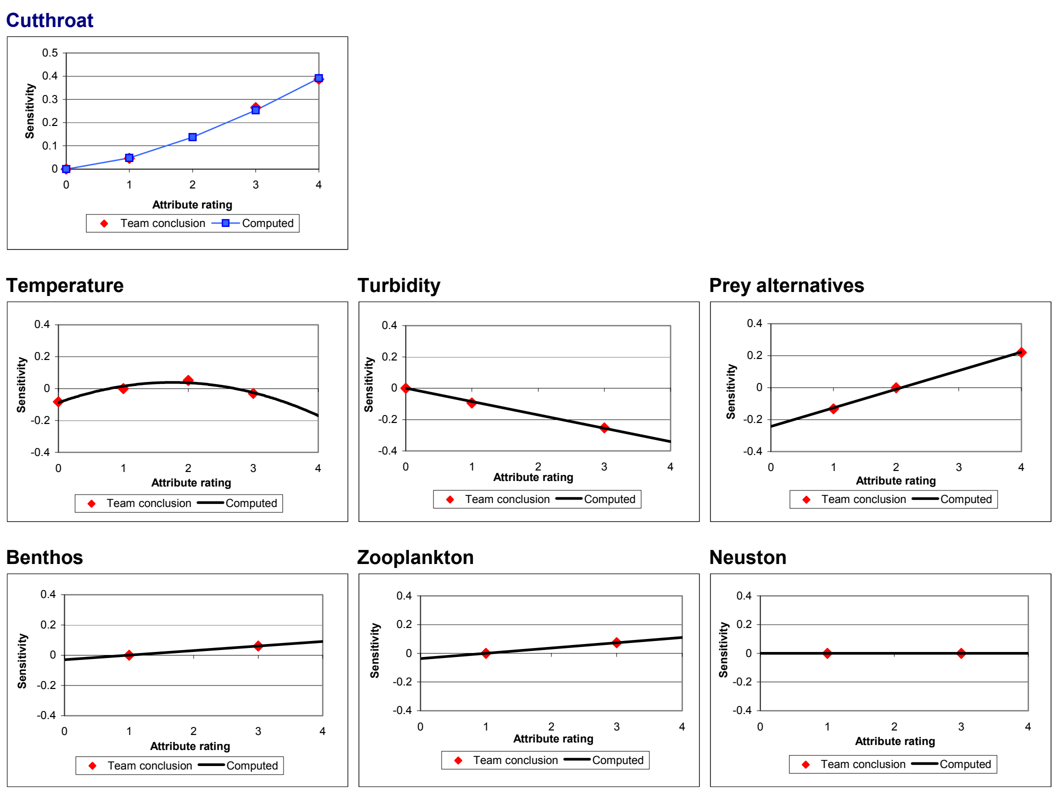
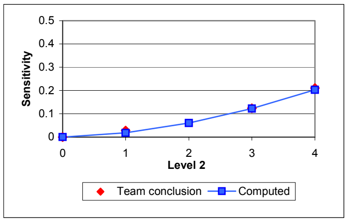
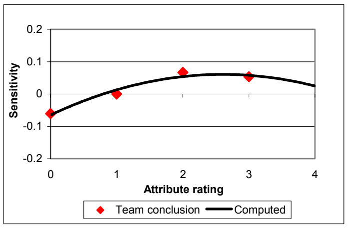


Figure C-5. Sensitivity curves for Cutthroat in limnetic areas.

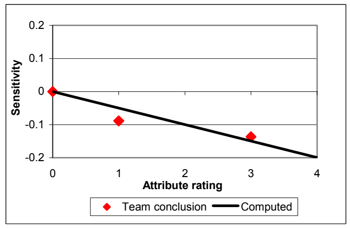
Pikeminnow



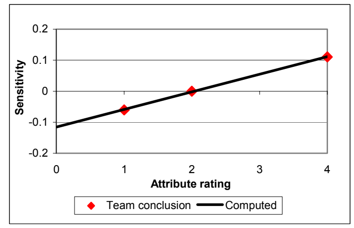
Temperature



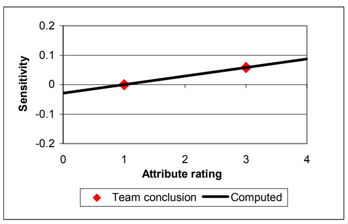
Turbidity



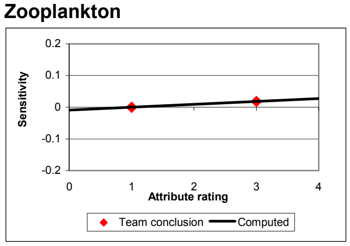
Prey alternatives



Benthos



Zooplankton



Neuston

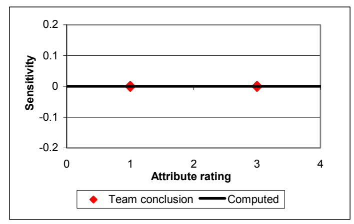
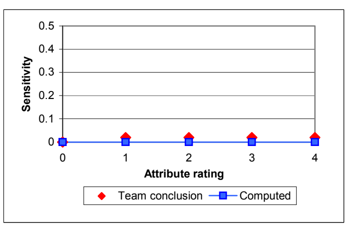
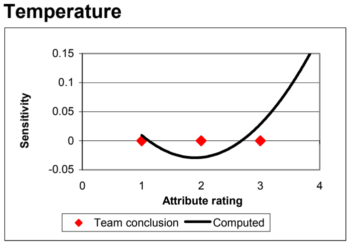


Figure C-6. Sensitivity curves for Pikeminnow in limnetic areas.

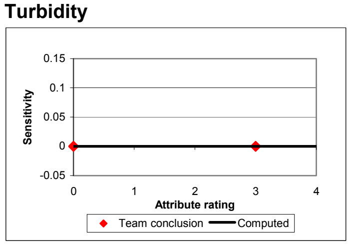
Perch



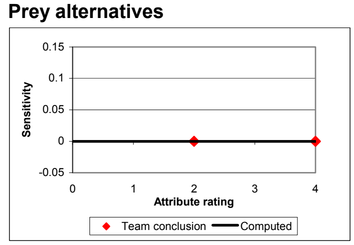
Temperature



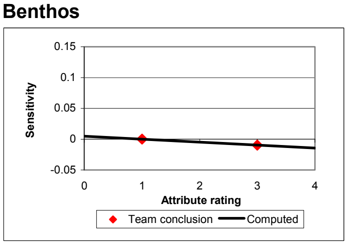
Turbidity



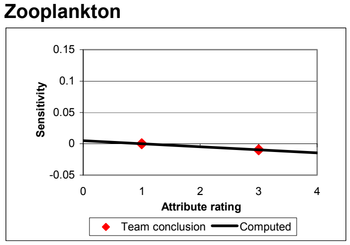
Prey alternatives



Benthos



Zooplankton



Neuston

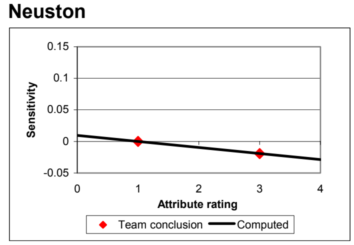
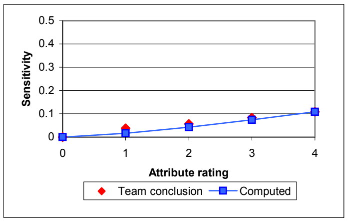
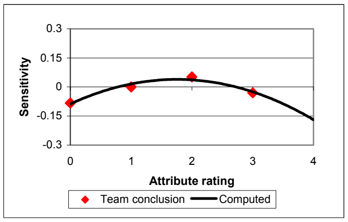


Figure C-7. Sensitivity curves for Perch in limnetic areas.

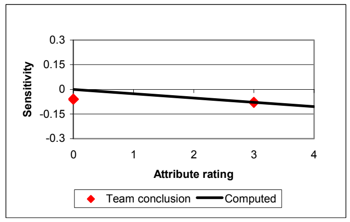
Rainbow



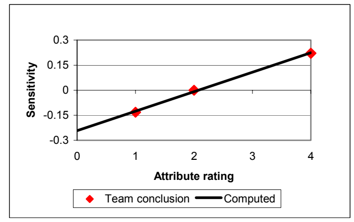
Temperature



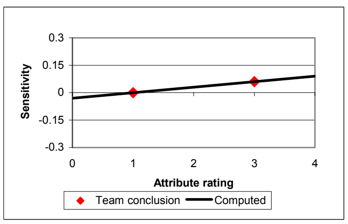
Turbidity



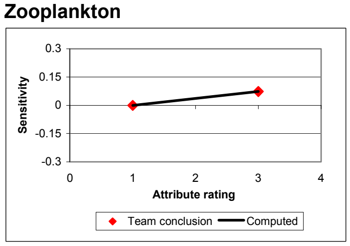
Prey alternatives



Benthos



Zooplankton



Neuston

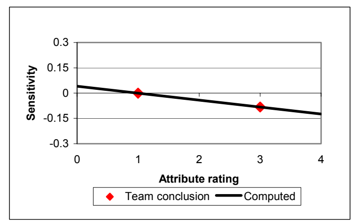
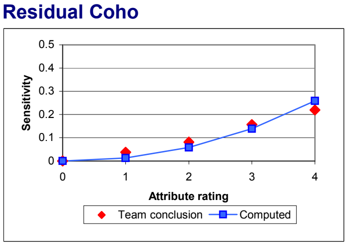
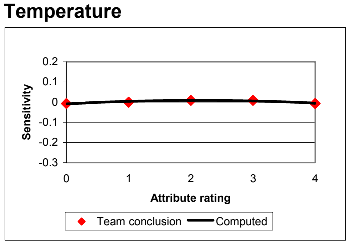


Figure C-8. Sensitivity curves for Rainbow in limnetic areas.

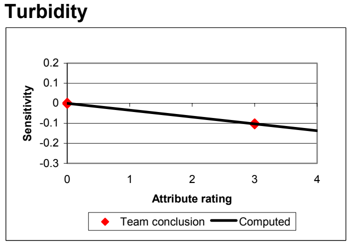
Residual Coho



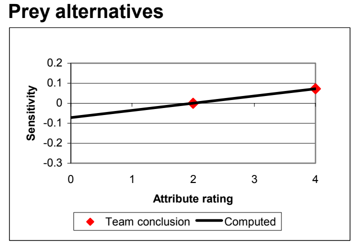
Temperature



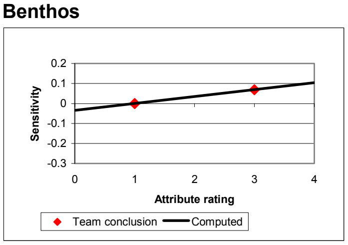
Turbidity



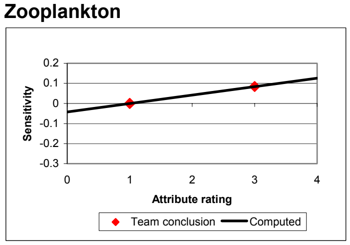
Prey alternatives



Benthos



Zooplankton



Neuston

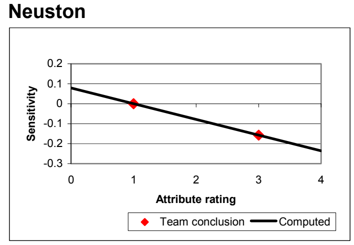
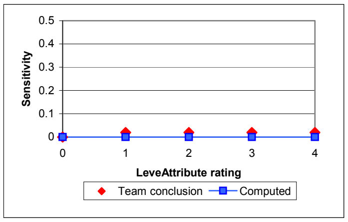
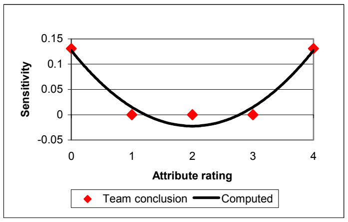


Figure C-9. Sensitivity curves for Residual Coho in limnetic areas.

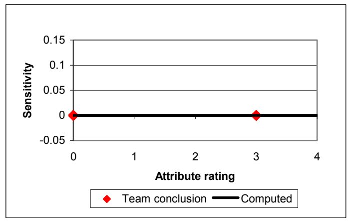
Hatchery Coho



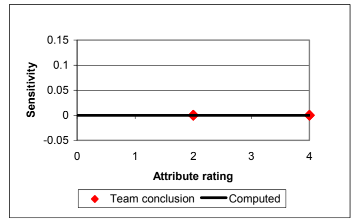
Temperature



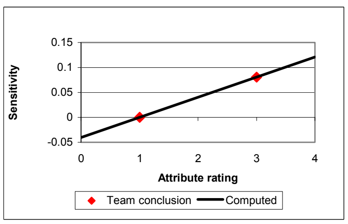
Turbidity



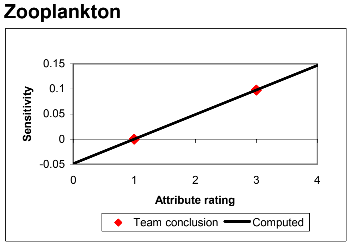
Prey alternatives



Benthos



Zooplankton



Neuston

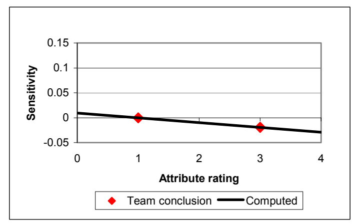
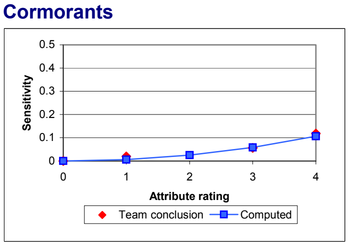
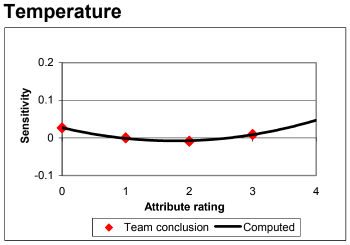


Figure C-10. Sensitivity curves for hatchery Coho in limnetic areas.

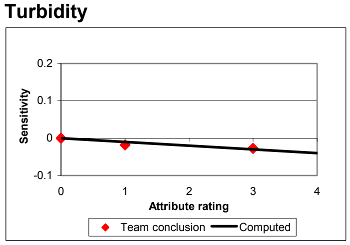
Cormorants



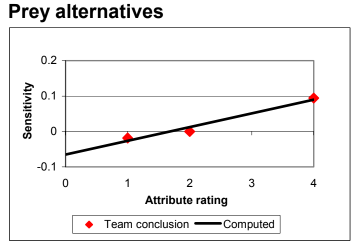
Temperature



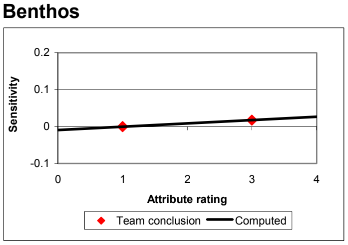
Turbidity



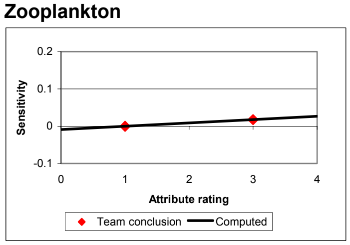
Prey alternatives



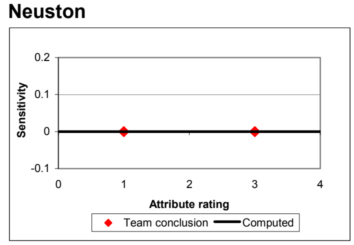
Benthos



Zooplankton

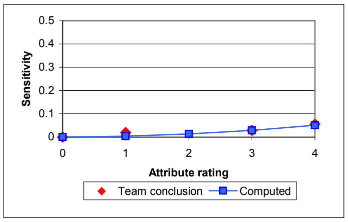


Neuston

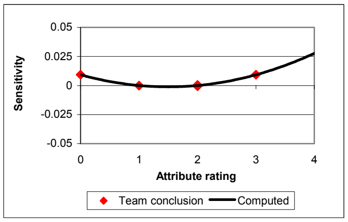


Figures C-11. Sensitivity curves for Cormorants in limnetic areas.

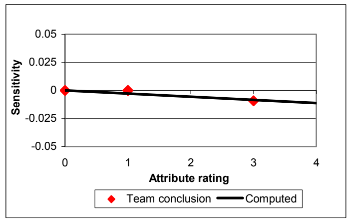
Grebes



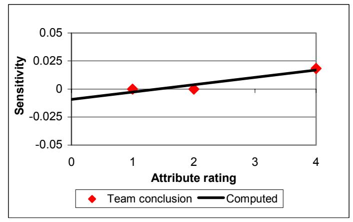
Temperature



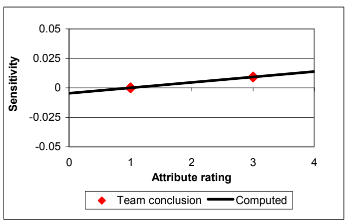
Turbidity



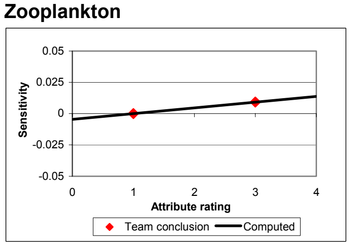
Prey alternatives



Benthos



Zooplankton



Neuston

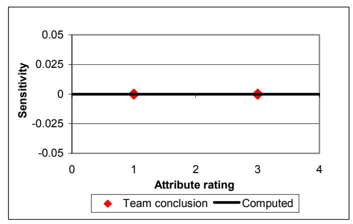
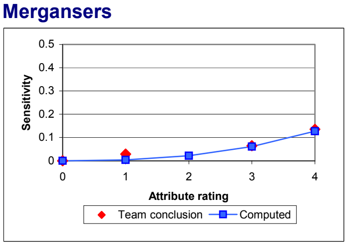
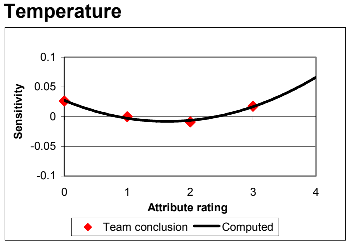


Figure C-12. Sensitivity curves for Grebes in limnetic areas.

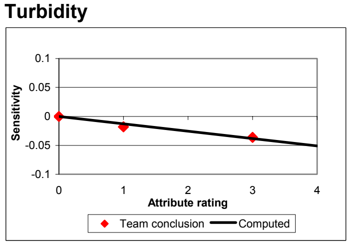
Mergansers



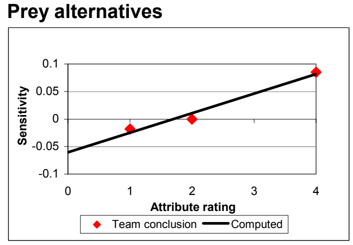
Temperature



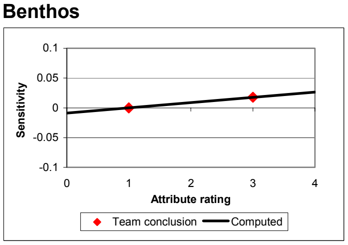
Turbidity



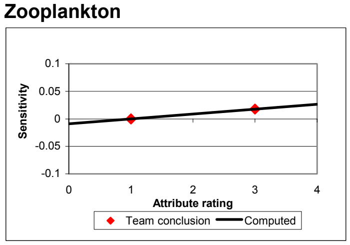
Prey alternatives



Benthos



Zooplankton



Neuston

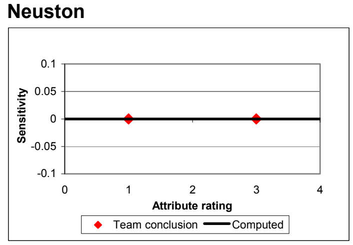
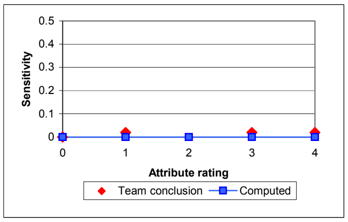
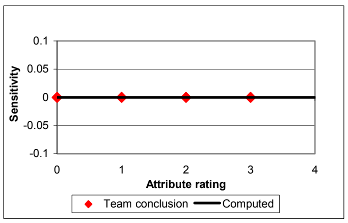


Figure C-13. Sensitivity curves for Mergansers in limnetic areas.

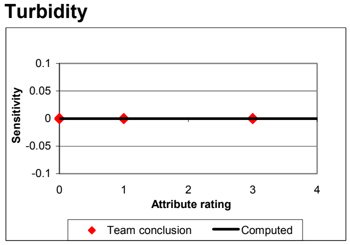
Gulls



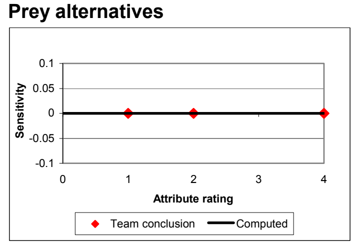
Temperature



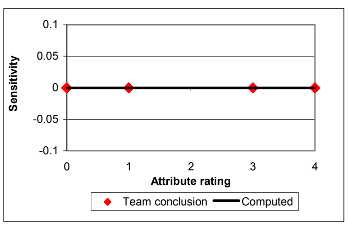
Turbidity



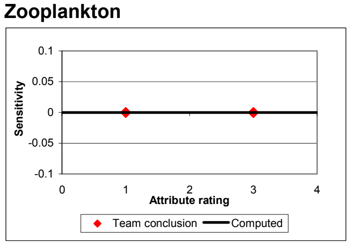
Prey alternatives



Benthos



Zooplankton



Neuston

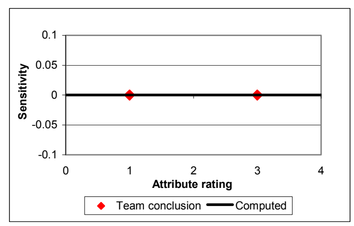


Figure C-14. Sensitivity curves for Gulls in limnetic areas.

Cutthroat trout
Base (reference) mortality rates
Reference conditions for all modifying attributes (e.g., temperature, turbidity, prey alternatives)

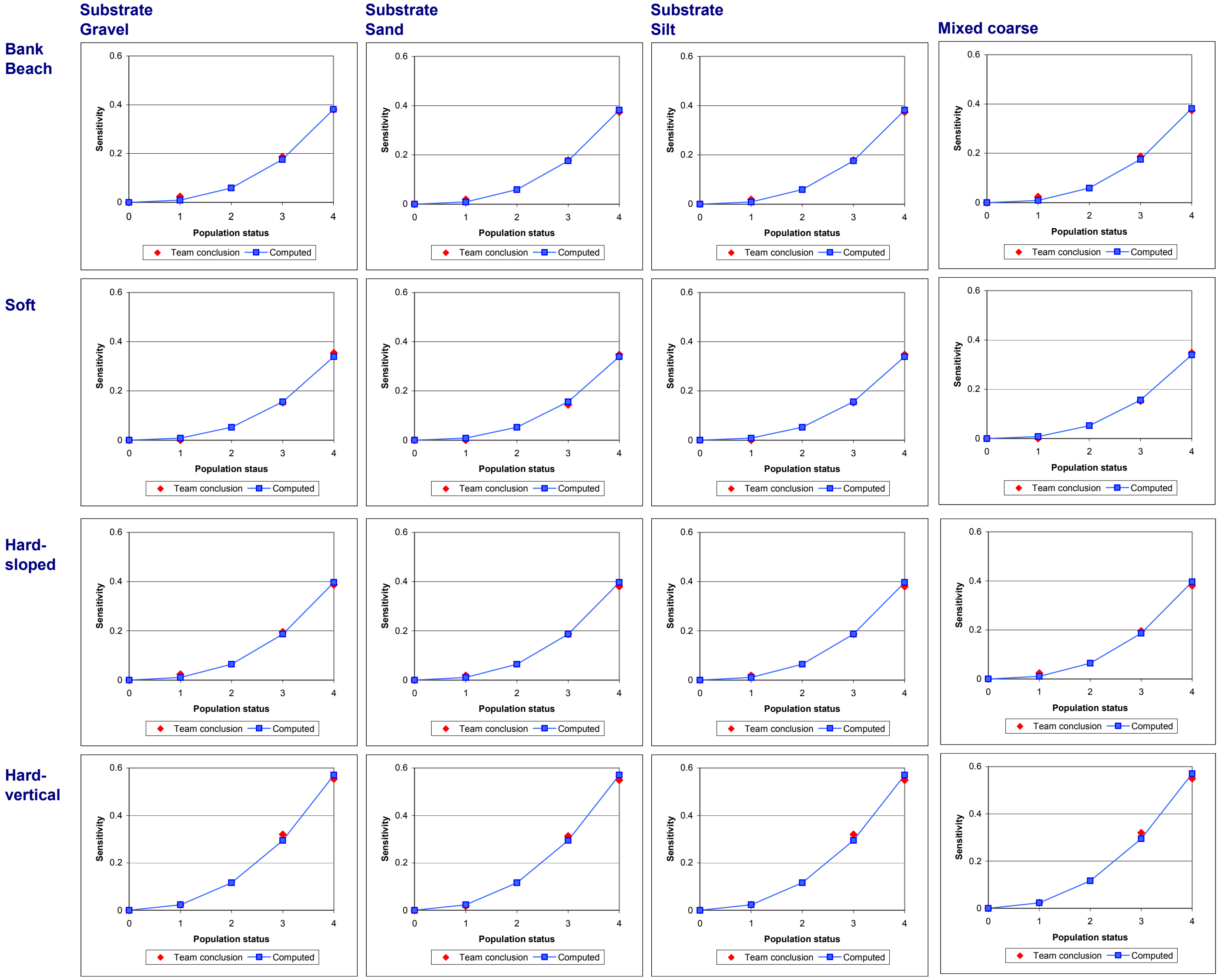


Figure C-15. Sensitivity curves for Cutthroat in base littoral.

Sculpins
Base (reference) mortality rates

Reference conditions for all modifying attributes (e.g., temperature, turbidity, prey alternatives)

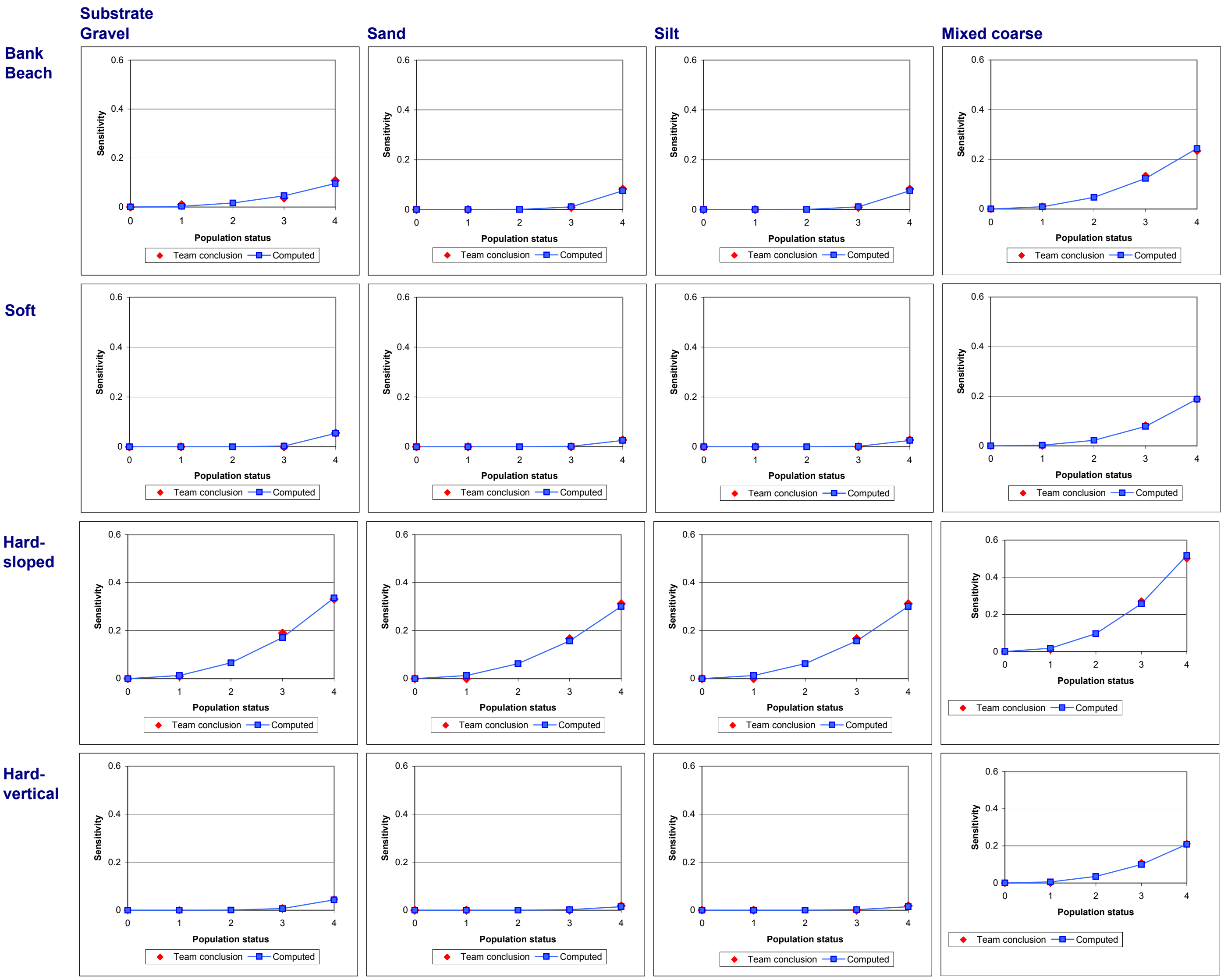


Figure C-16. Sensitivity curves for Sculpin in base littoral.

Pikeminnow
Base (reference) mortality rates

Reference conditions for all modifying attributes (e.g., temperature, turbidity, prey alternatives)

Substrate Gravel | Substrate Sand | Substrate Silt | Substrate Mixed coarse

Bank Beach

Soft

Hard-sloped

Hard-vertical

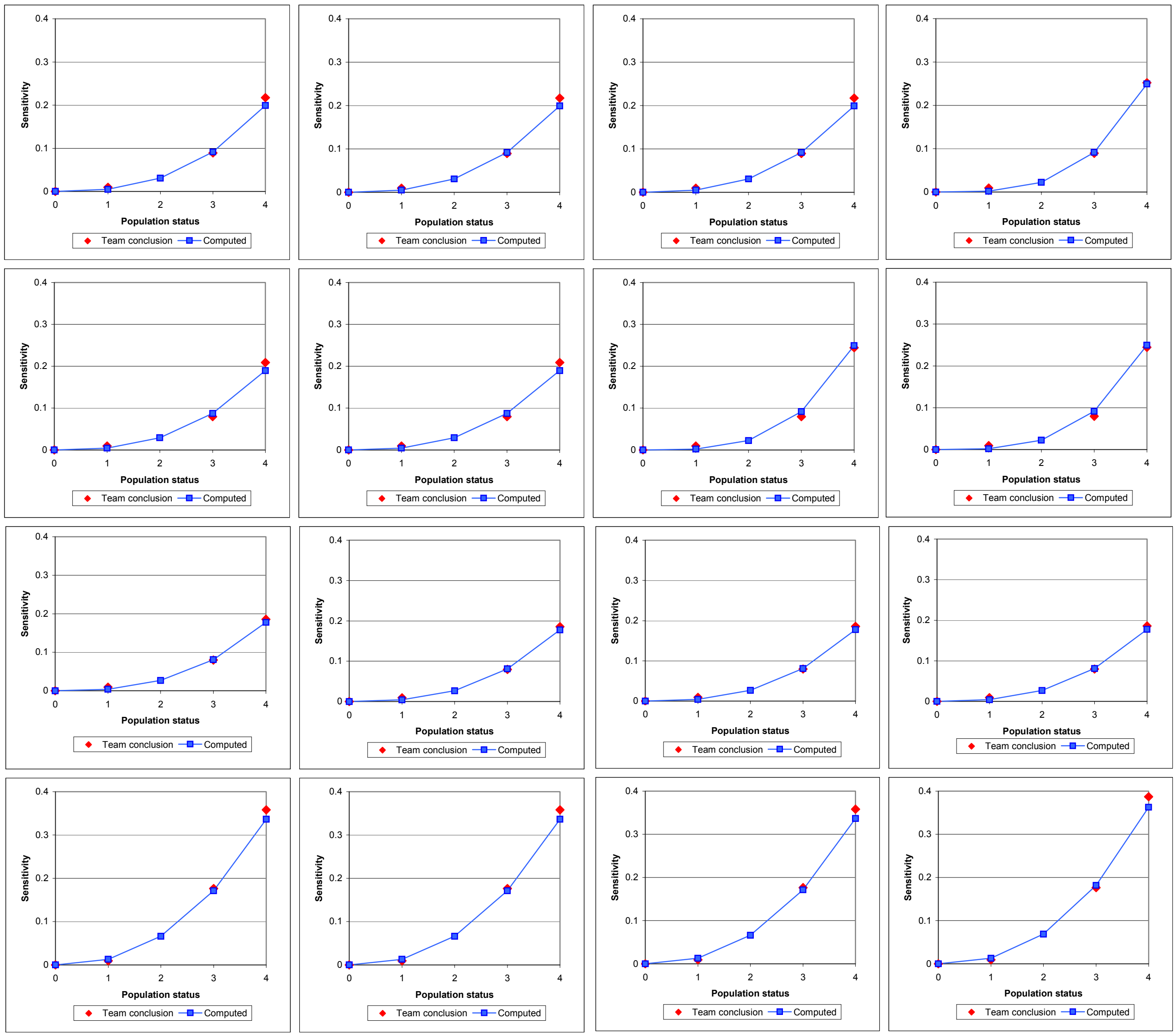


Figure C-17. Sensitivity curves for Pikeminnow in base littoral.

Rainbow

Base (reference) mortality rates

Reference conditions for all modifying attributes (e.g., temperature, turbidity, prey alternatives)

Columns: **Substrate Gravel** | **Substrate Sand** | **Substrate Silt** | **Substrate Mixed coarse**

Rows: **Bank Beach** | **Soft** | **Hard-sloped** | **Hard-vertical**

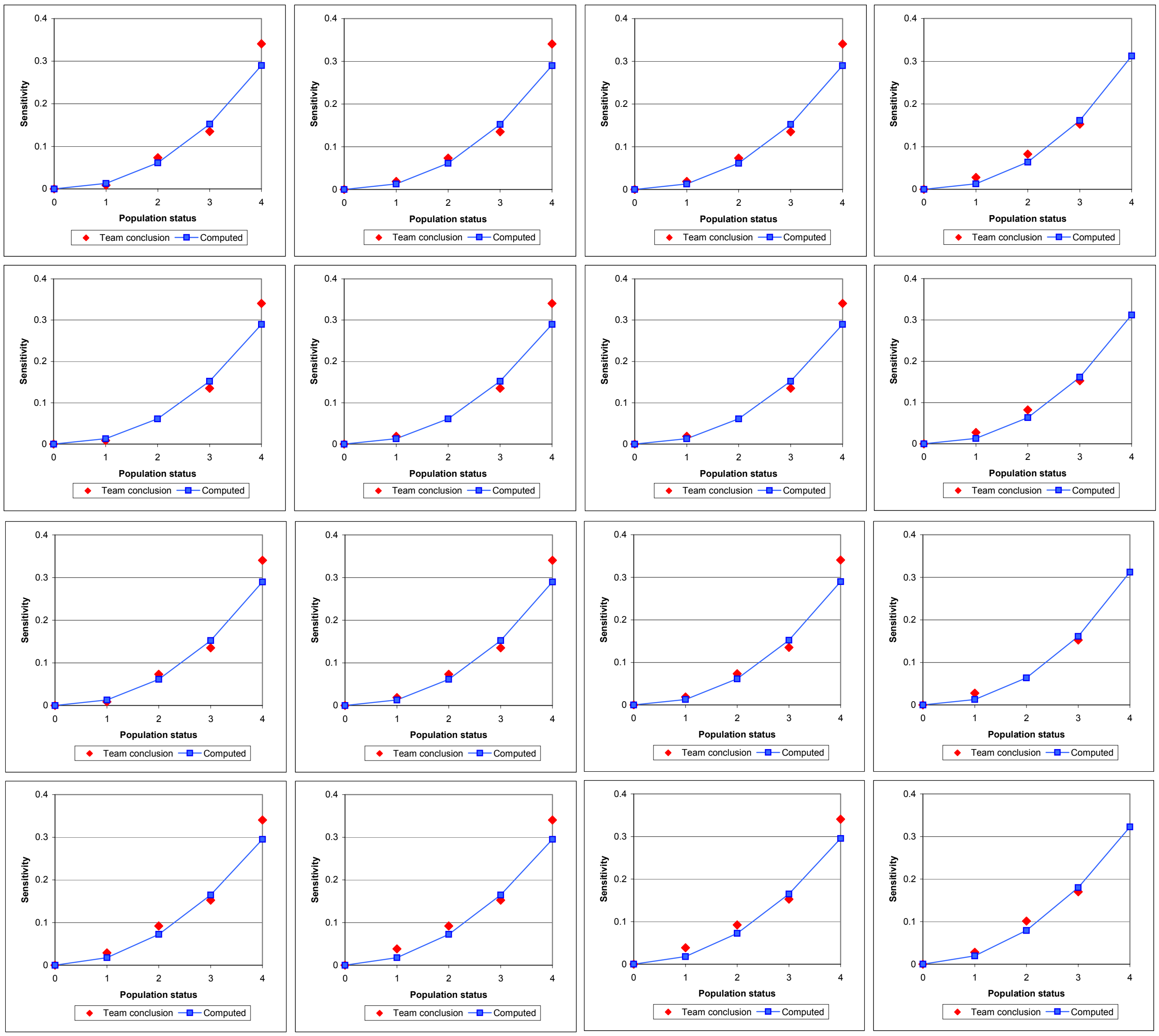


Figure C-18. Sensitivity curves for Rainbow in base littoral.

Crayfish
Base (reference) mortality rates
Reference conditions for all modifying attributes (e.g., temperature, turbidity, prey alternatives)

Substrate Gravel | **Substrate Sand** | **Substrate Silt** | **Substrate Mixed coarse**

Bank Beach

Soft

Hard-sloped

Hard-vertical

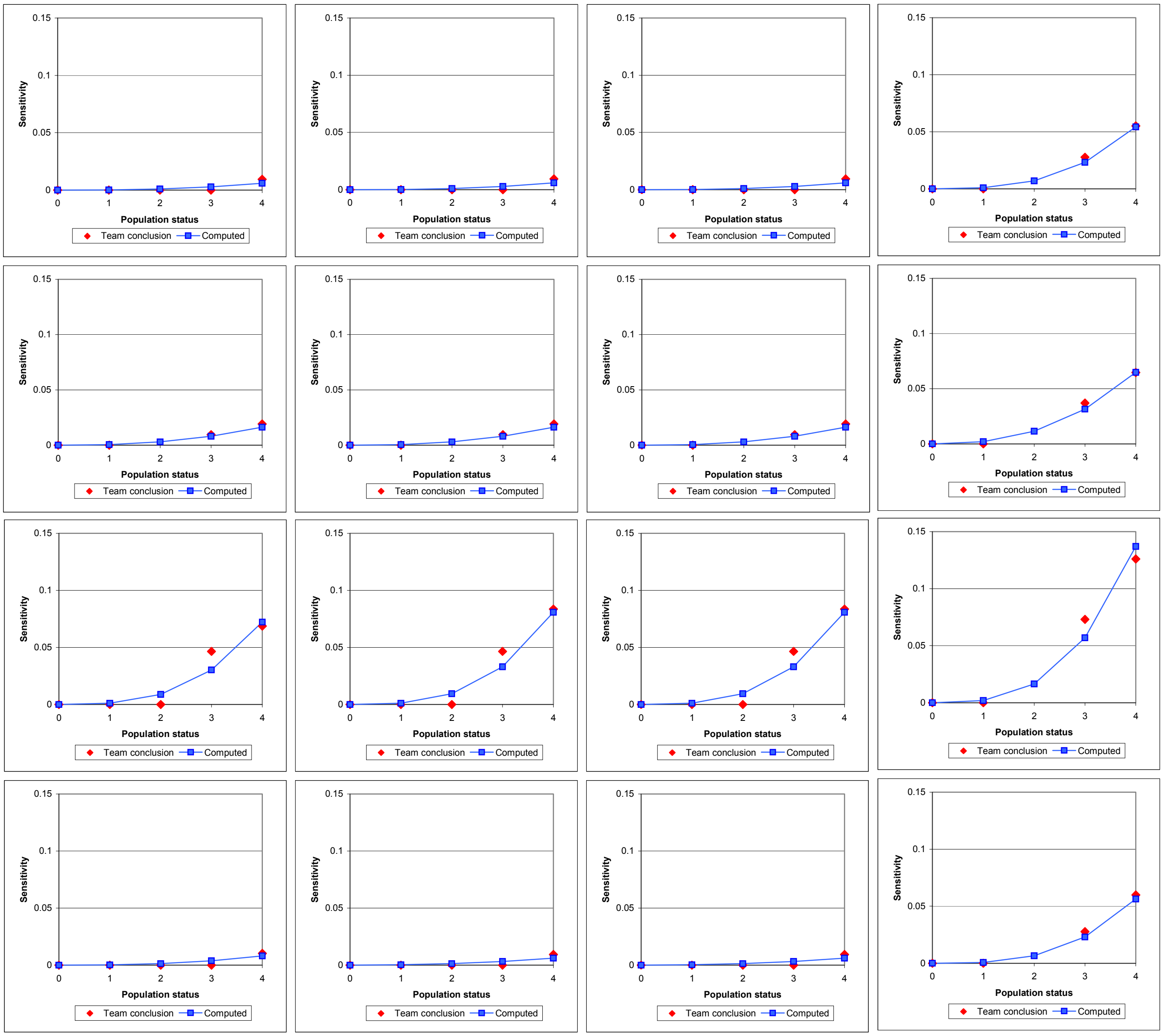


Figure C-19. Sensitivity curves for Crayfish in base littoral.

Bass
Base (reference) mortality rates

Reference conditions for all modifying attributes (e.g., temperature, turbidity, prey alternatives)

Substrate Gravel | **Substrate Sand** | **Substrate Silt** | **Substrate Mixed coarse**

Bank Beach

Soft

Hard-sloped

Hard-vertical

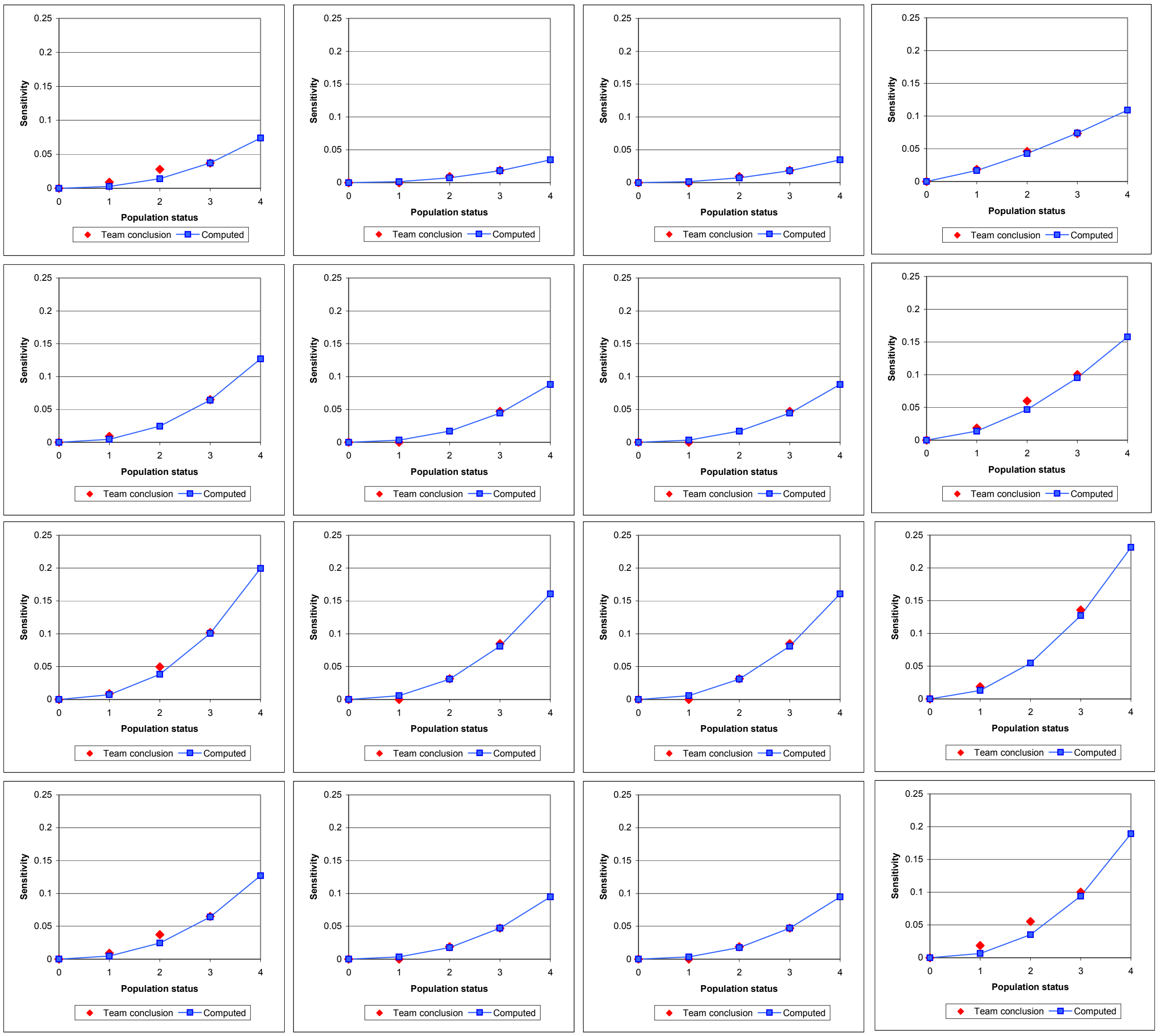


Figure C-20. Sensitivity curves for Bass in base littoral.

Perch

Base (reference) mortality rates

Reference conditions for all modifying attributes (e.g., temperature, turbidity, prey alternatives)

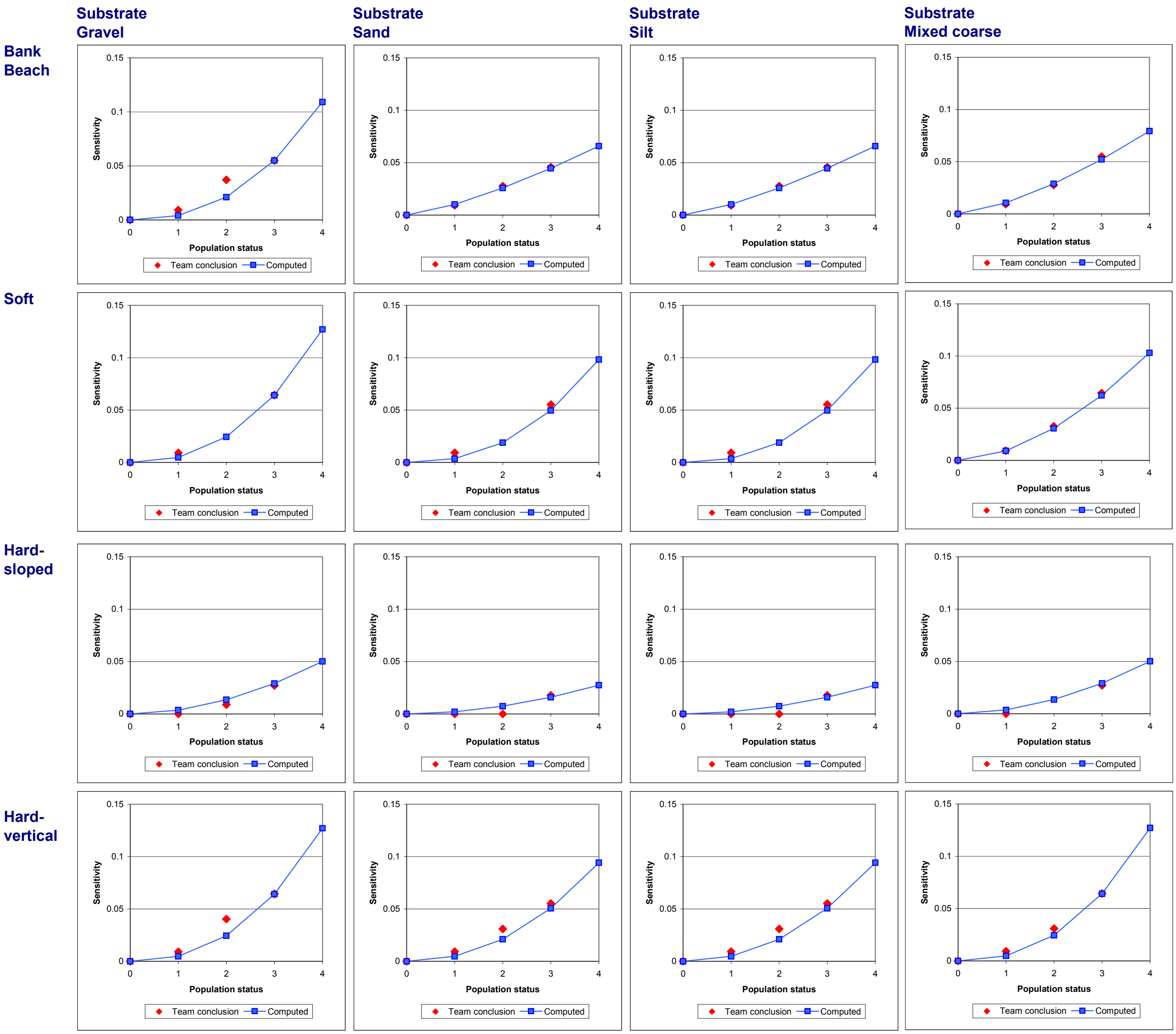


Figure C-21. Sensitivity curves for Perch in base littoral.

Brown Bullhead
Base (reference) mortality rates

Reference conditions for all modifying attributes (e.g., temperature, turbidity, prey alternatives)

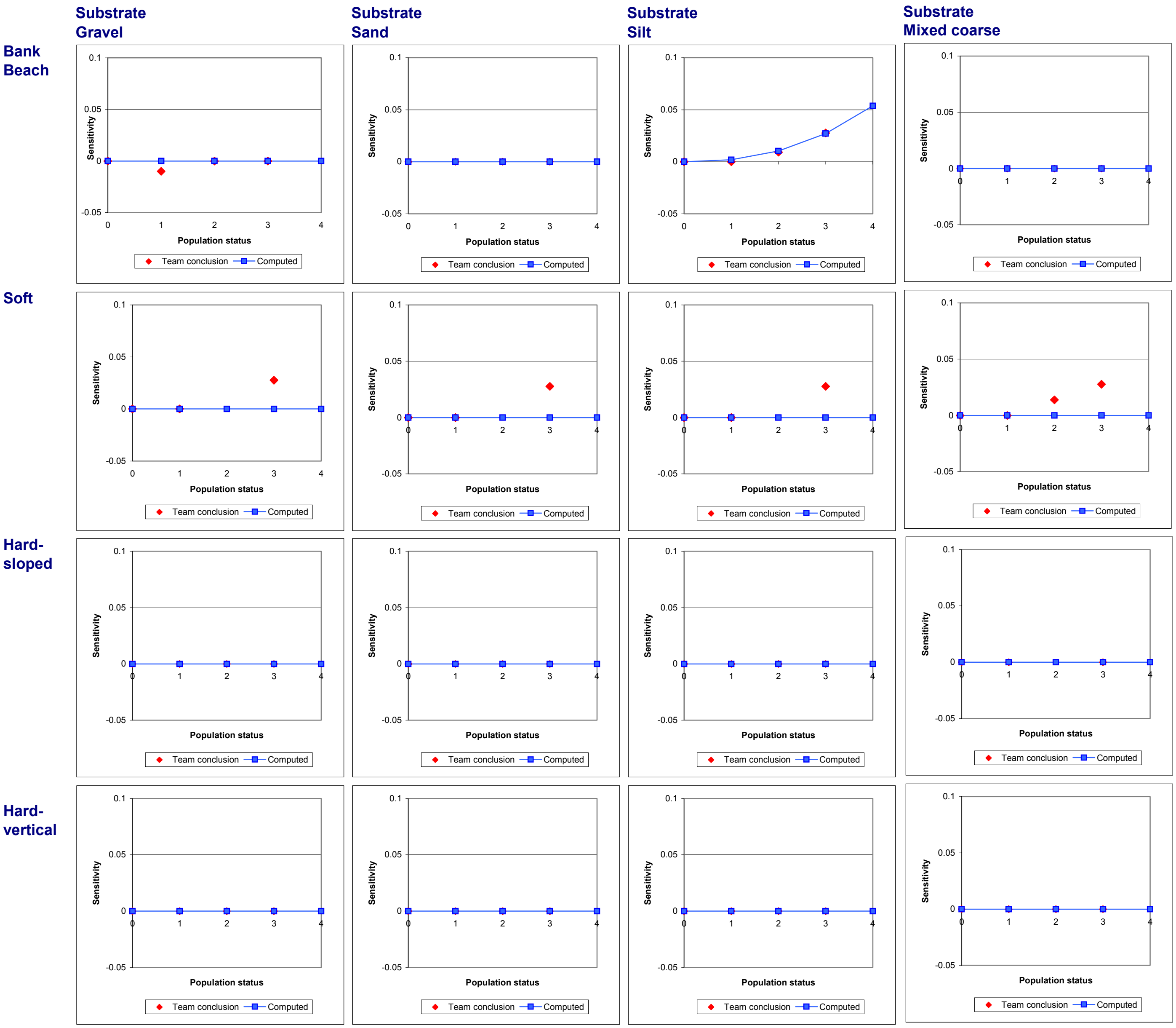


Figure C-22. Sensitivity curves for Brown bullhead in base littoral.

Residual Coho
Base (reference) mortality rates

Reference conditions for all modifying attributes (e.g., temperature, turbidity, prey alternatives)

Substrate Gravel | Substrate Sand | Substrate Silt | Substrate Mixed coarse

Bank Beach

Soft

Hard-sloped

Hard-vertical

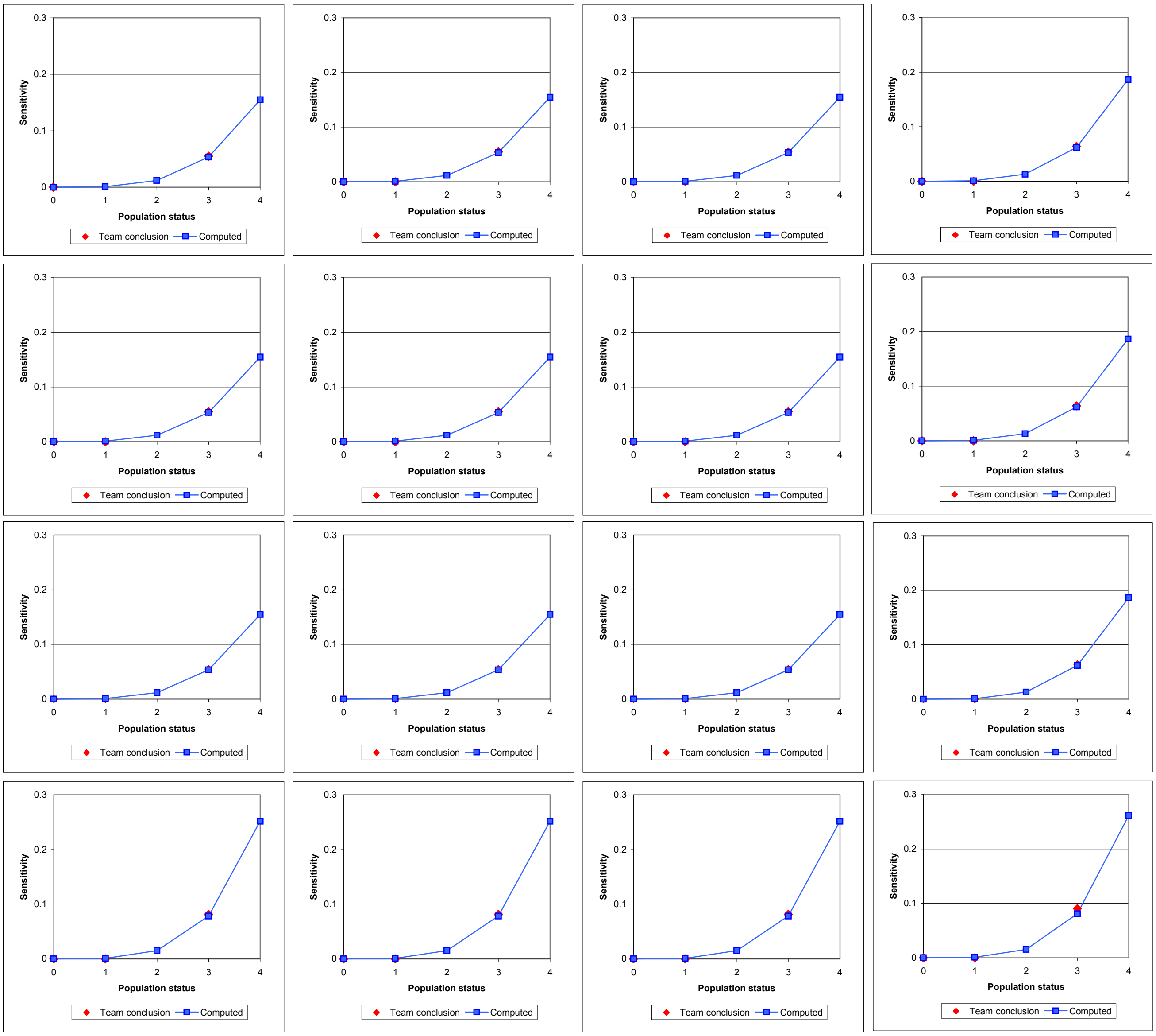


Figure C-23. Sensitivity curves for residual coho in base littoral.

Hatchery Coho
Base (reference) mortality rates
Reference conditions for all modifying attributes (e.g., temperature, turbidity, prey alternatives)

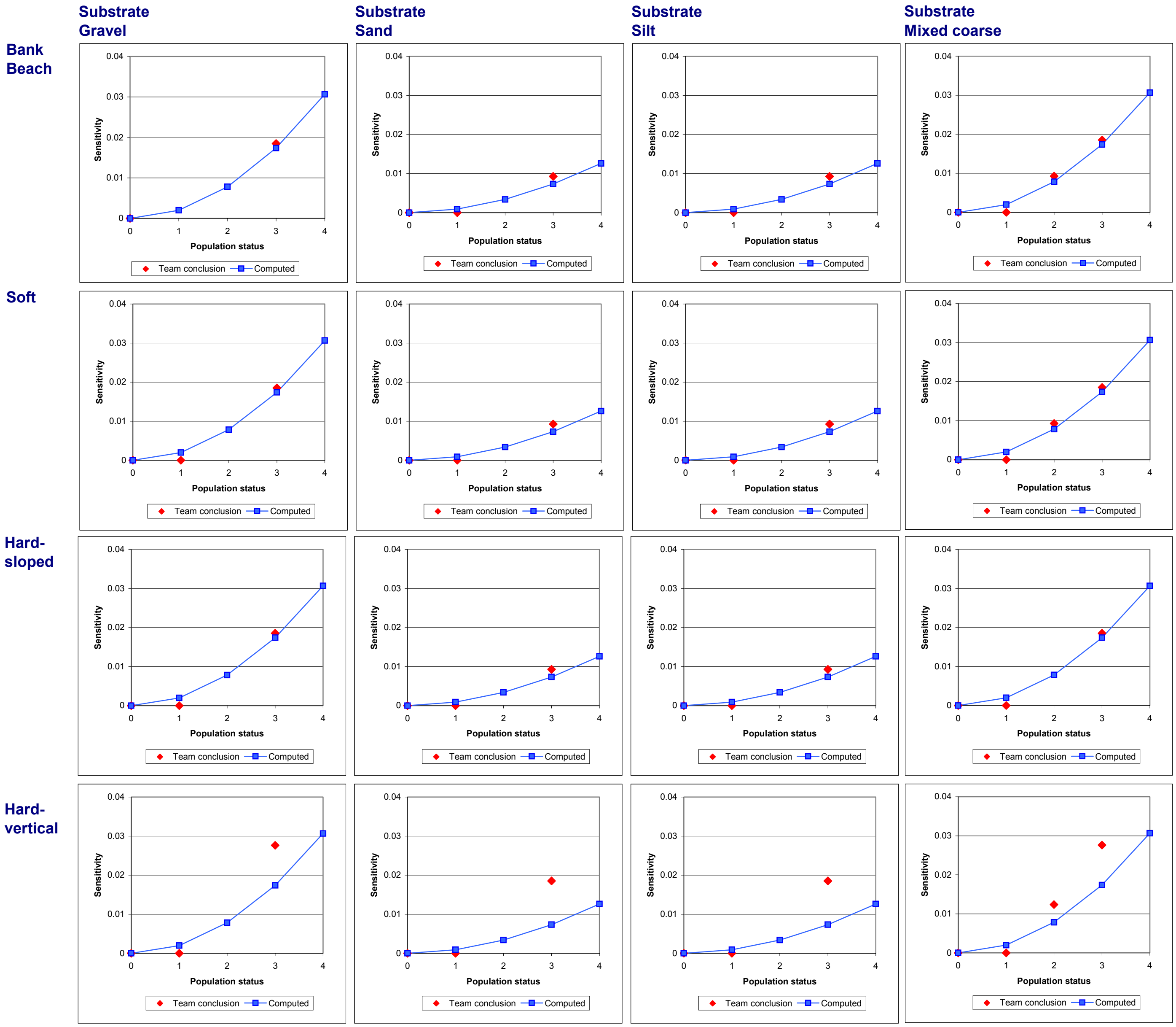


Figure C-24. Sensitivity curves for hatchery coho in base littoral.

Grebes

Base (reference) mortality rates

Reference conditions for all modifying attributes (e.g., temperature, turbidity, prey alternatives)

	Substrate Gravel	Substrate Sand	Substrate Silt	Substrate Mixed coarse
Bank Beach				
Soft				
Hard-sloped				
Hard-vertical				

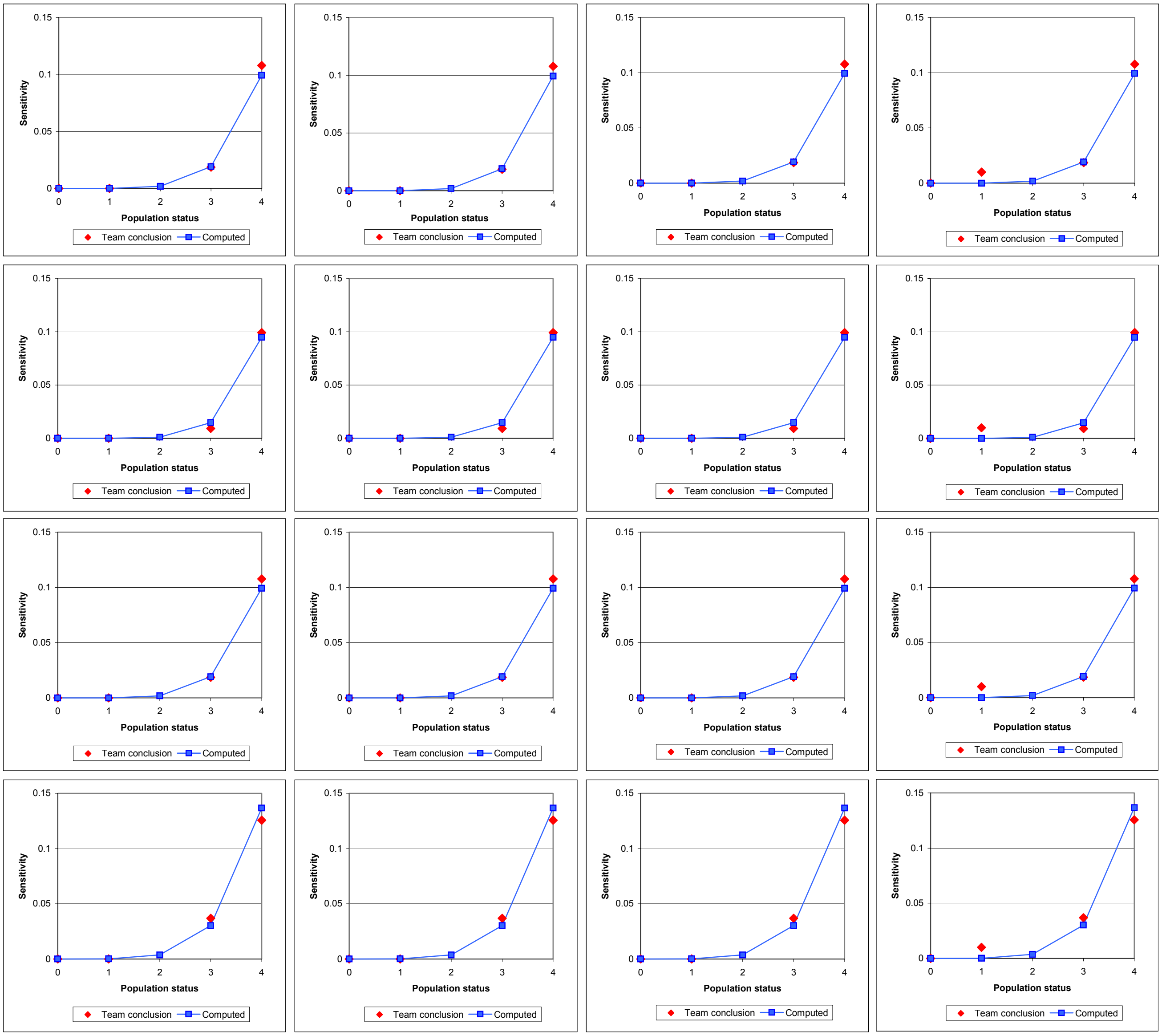


Figure C-25. Sensitivity curves for Grebes in base littoral.

Cormorants
Base (reference) mortality rates

Reference conditions for all modifying attributes (e.g., temperature, turbidity, prey alternatives)

Columns: **Substrate Gravel** | **Substrate Sand** | **Substrate Silt** | **Substrate Mixed coarse**

Rows: **Bank Beach** | **Soft** | **Hard-sloped** | **Hard-vertical**

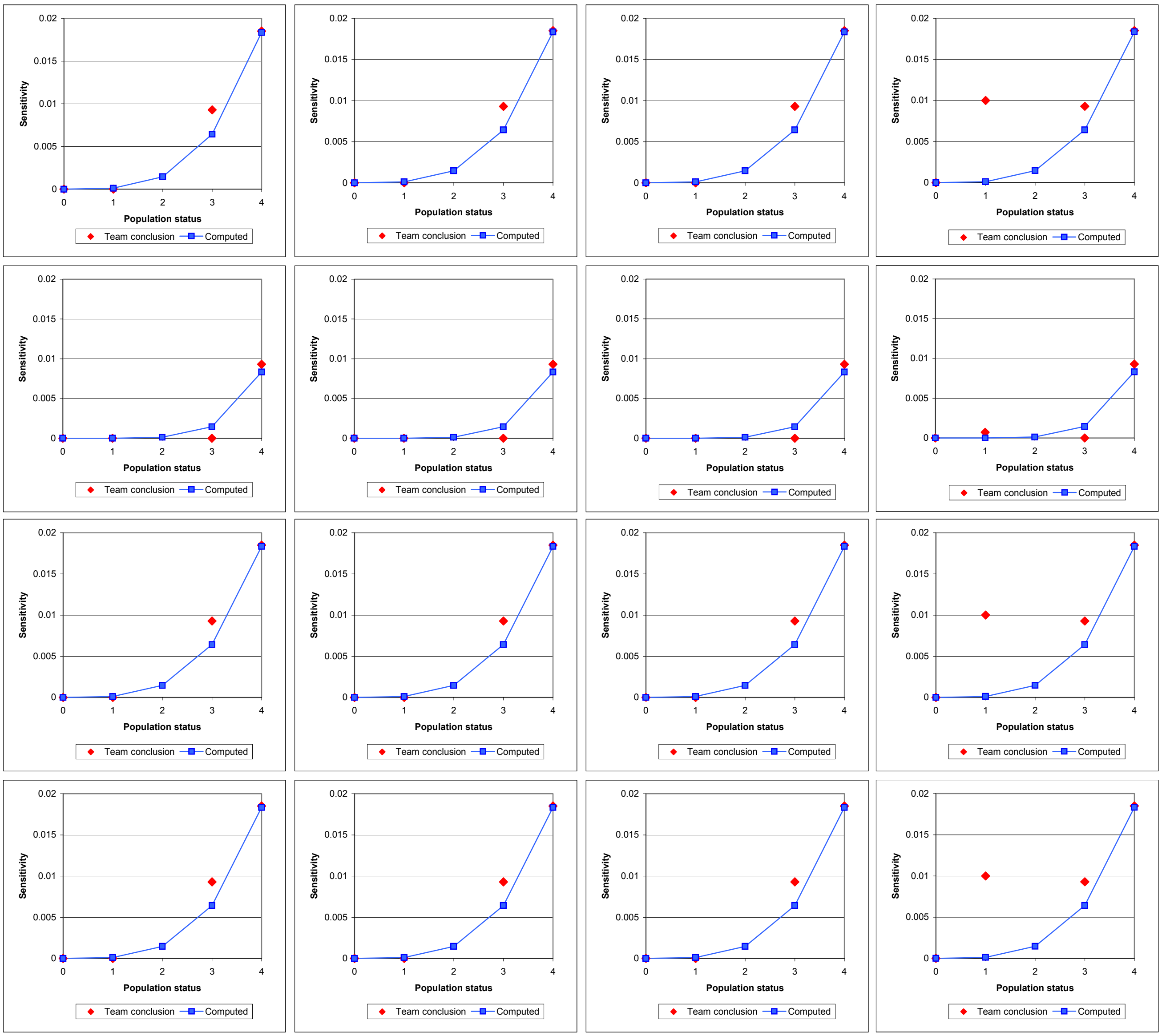


Figure C-26. Sensitivity curves for Cormorants in base littoral.

Herons
Base (reference) mortality rates
Reference conditions for all modifying attributes (e.g., temperature, turbidity, prey alternatives)

Substrate Gravel | Substrate Sand | Substrate Silt | Substrate Mixed coarse

Rows: Bank Beach; Soft; Hard-sloped; Hard-vertical

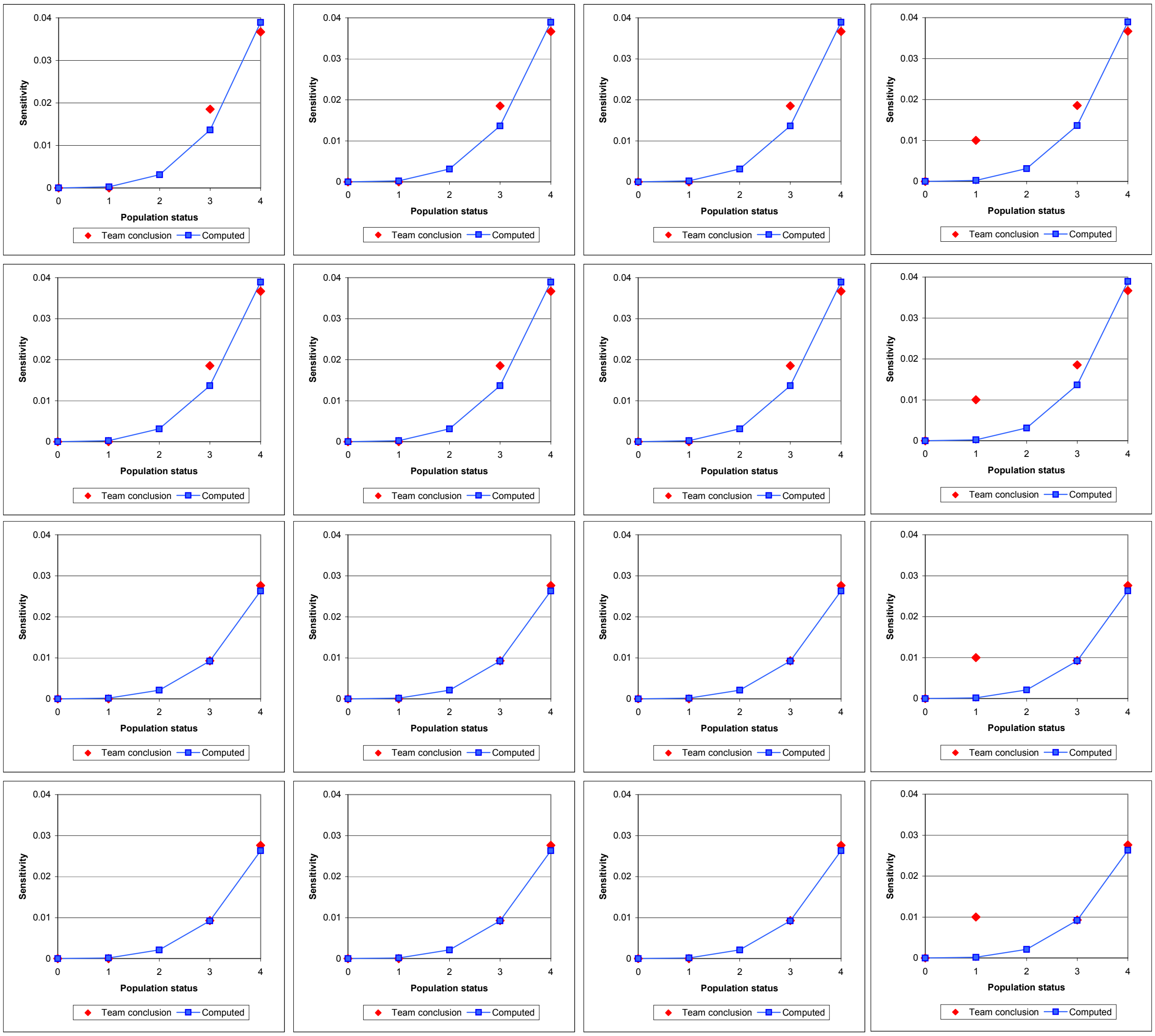


Figure C-27. Sensitivity curves for Herons in base littoral.

Mergansers
Base (reference) mortality rates
Reference conditions for all modifying attributes (e.g., temperature, turbidity, prey alternatives)

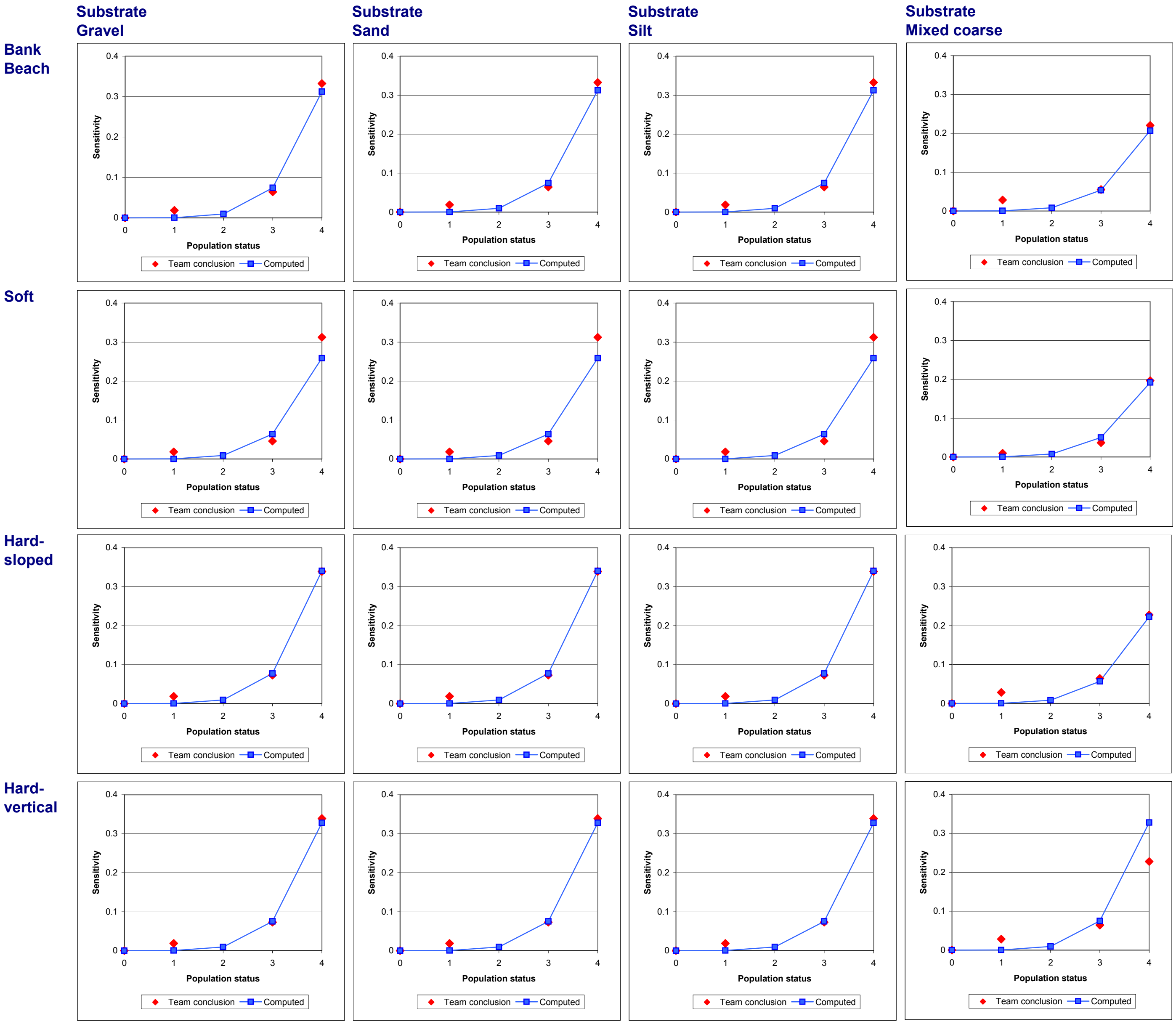


Figure C-28. Sensitivity curves for Mergansers in base littoral.

Gulls
Base (reference) mortality rates

Reference conditions for all modifying attributes (e.g., temperature, turbidity, prey alternatives)

Columns: **Substrate Gravel** | **Substrate Sand** | **Substrate Silt** | **Substrate Mixed coarse**

Rows: **Bank Beach** | **Soft** | **Hard-sloped** | **Hard-vertical**

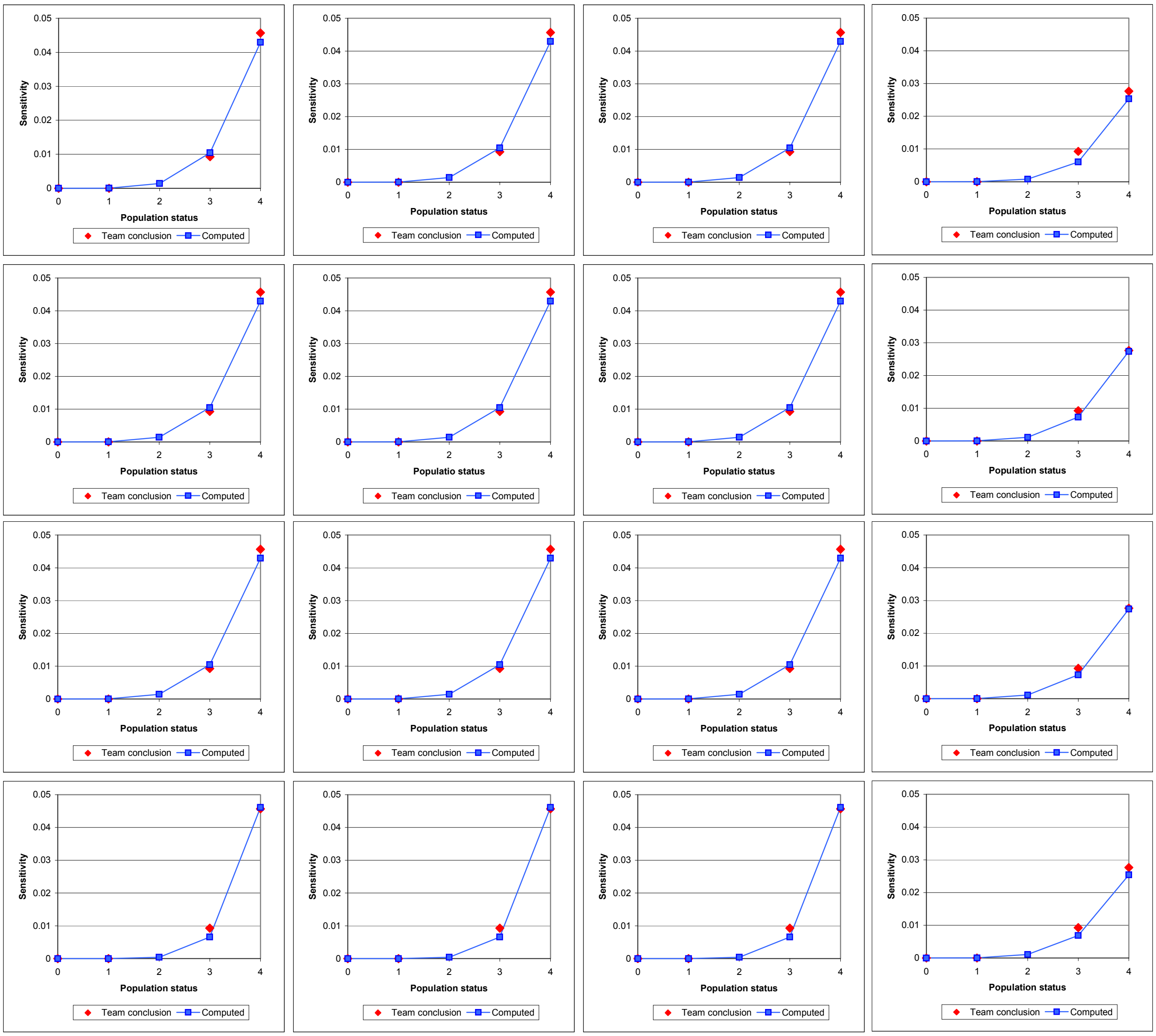


Figure C-29. Sensitivity curves for Gulls in base littoral.

Cutthroat
Modifying effects (as multiplicative factors)
Effects associated with reference or standard conditions (effects assumed the same for all bank and substrate types)

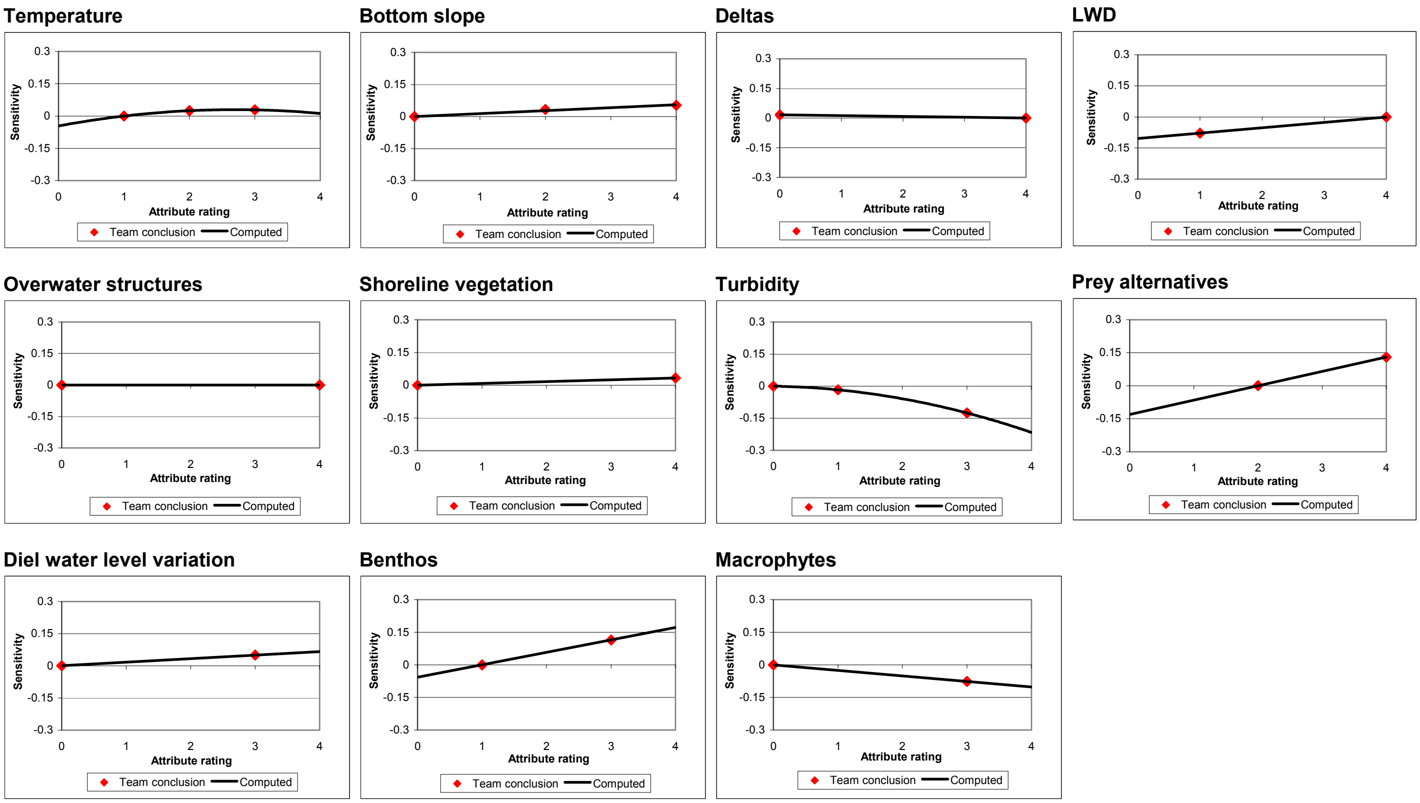


Figure C-30. Sensitivity curves for Cutthroat in modifiers littoral.

Sculpins
Modifying effects (as multiplicative factors)
Effects associated with reference or standard conditions (effects assumed the same for all bank and substrate types)

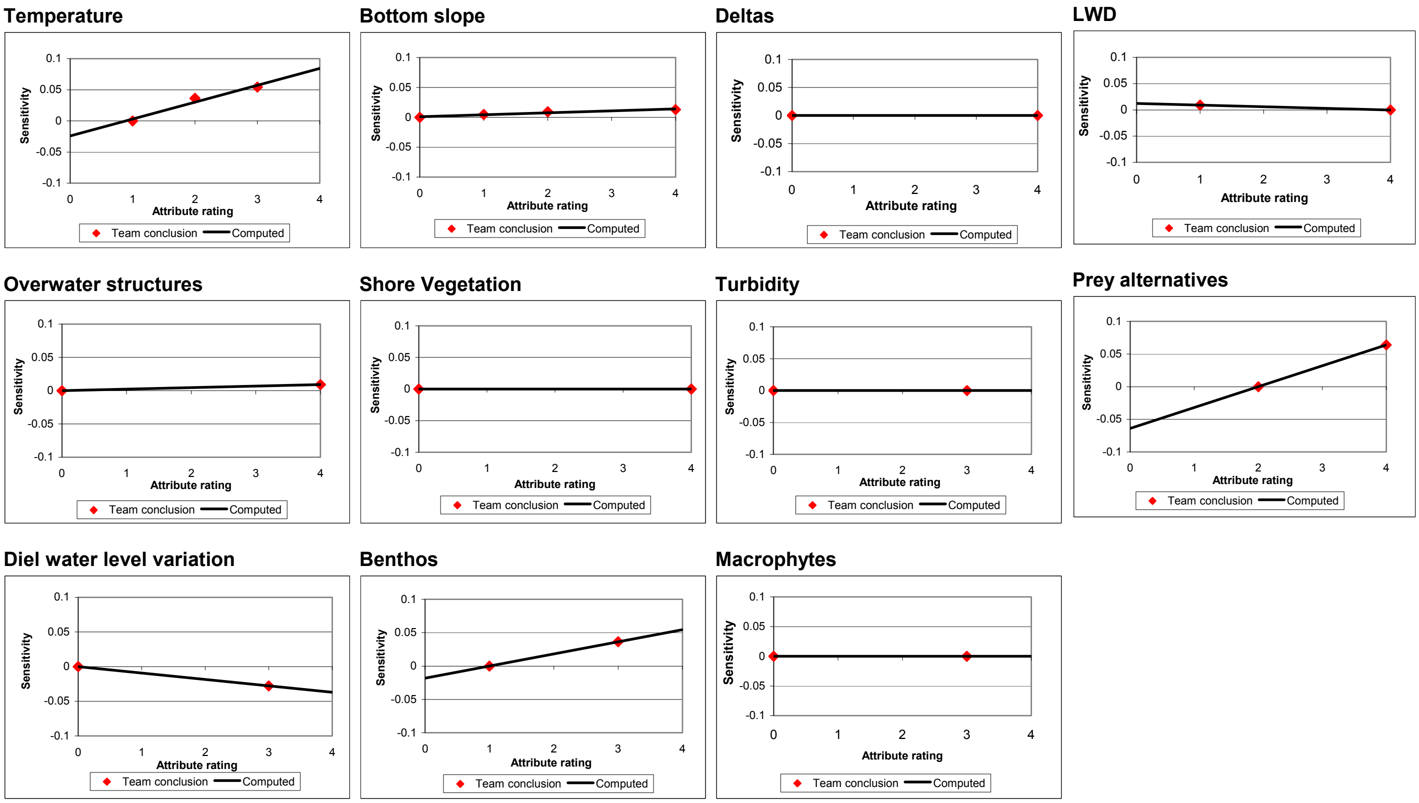


Figure C-31. Sensitivity curves for Sculpin in modifiers littoral.

Pikeminnow
Modifying effects (as multiplicative factors)

Effects associated with reference or standard conditions (effects assumed the same for all bank and substrate types)

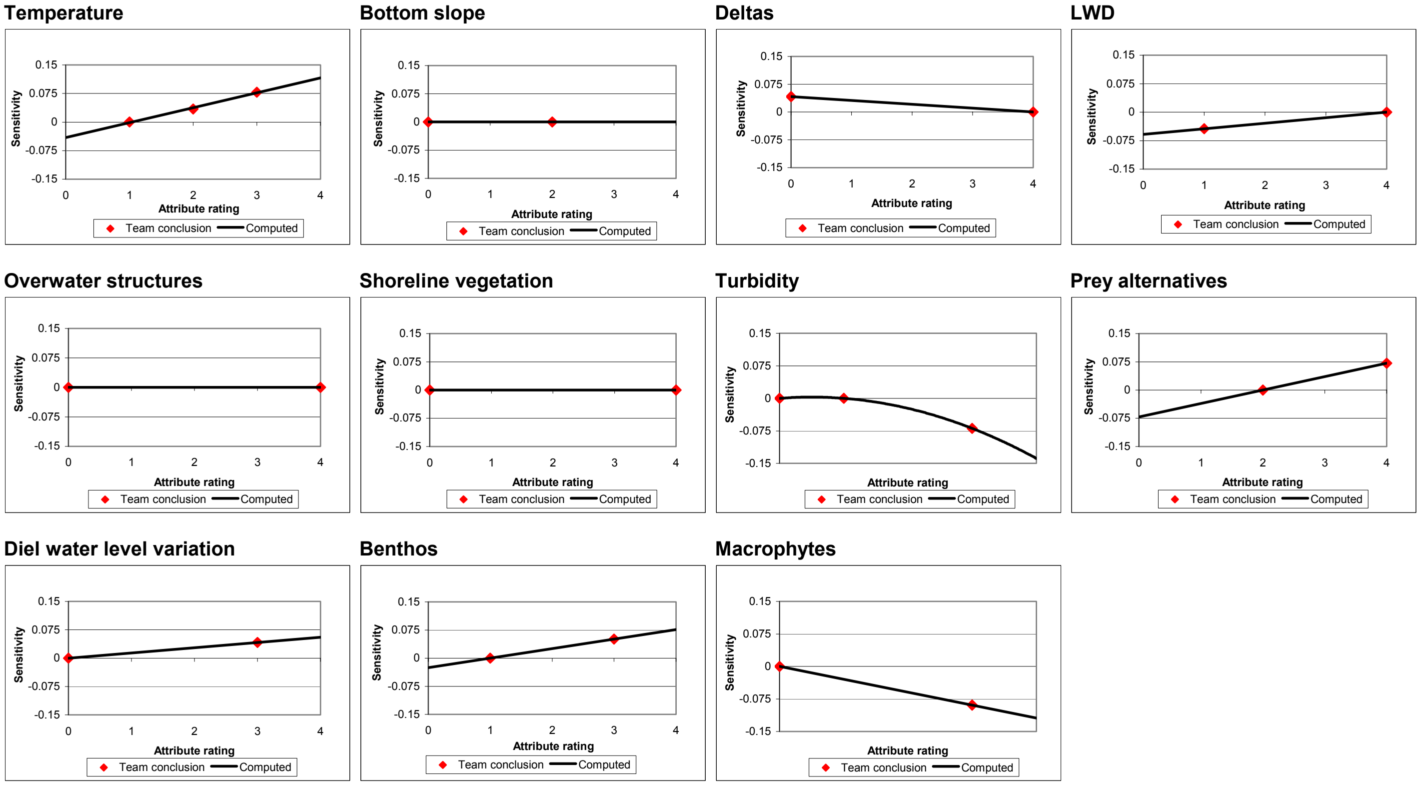


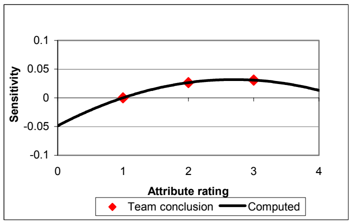
Figure C-32. Sensitivity curves for Pikeminnow in modifiers littoral.

Rainbow

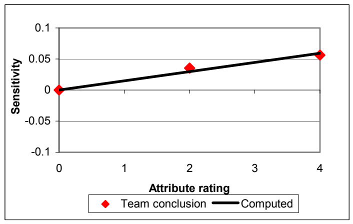
Modifying effects (as multiplicative factors)

Effects associated with reference or standard conditions (effects assumed the same for all bank and substrate types)

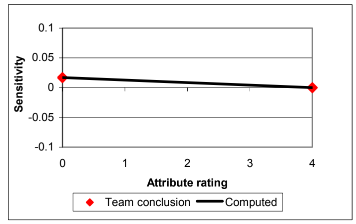
Temperature



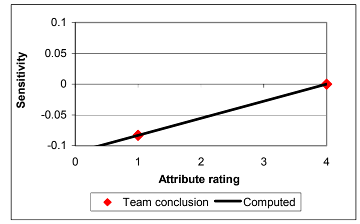
Bottom slope



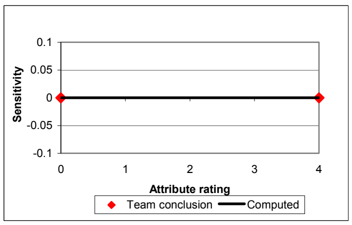
Deltas



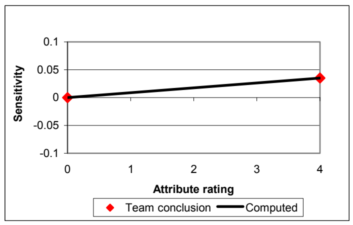
LWD



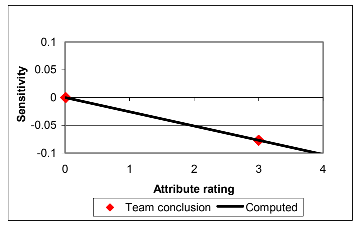
Overwater structures



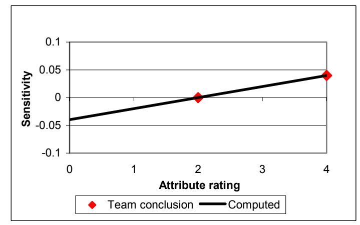
Shoreline vegetation



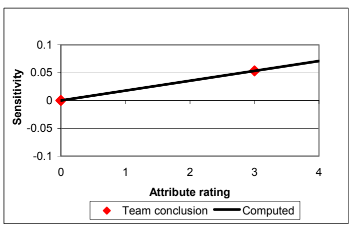
Turbidity



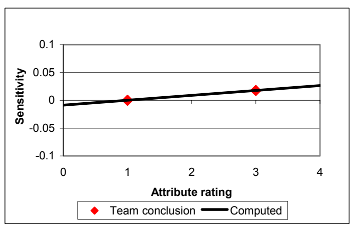
Prey alternatives



Diel water level variation



Benthos



Macrophytes

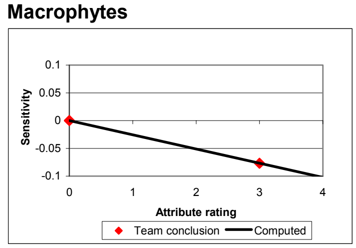


Figure C-33. Sensitivity curves for Rainbow in modifiers littoral.

Crayfish

Modifying effects (as multiplicative factors)

Effects associated with reference or standard conditions (effects assumed the same for all bank and substrate types)

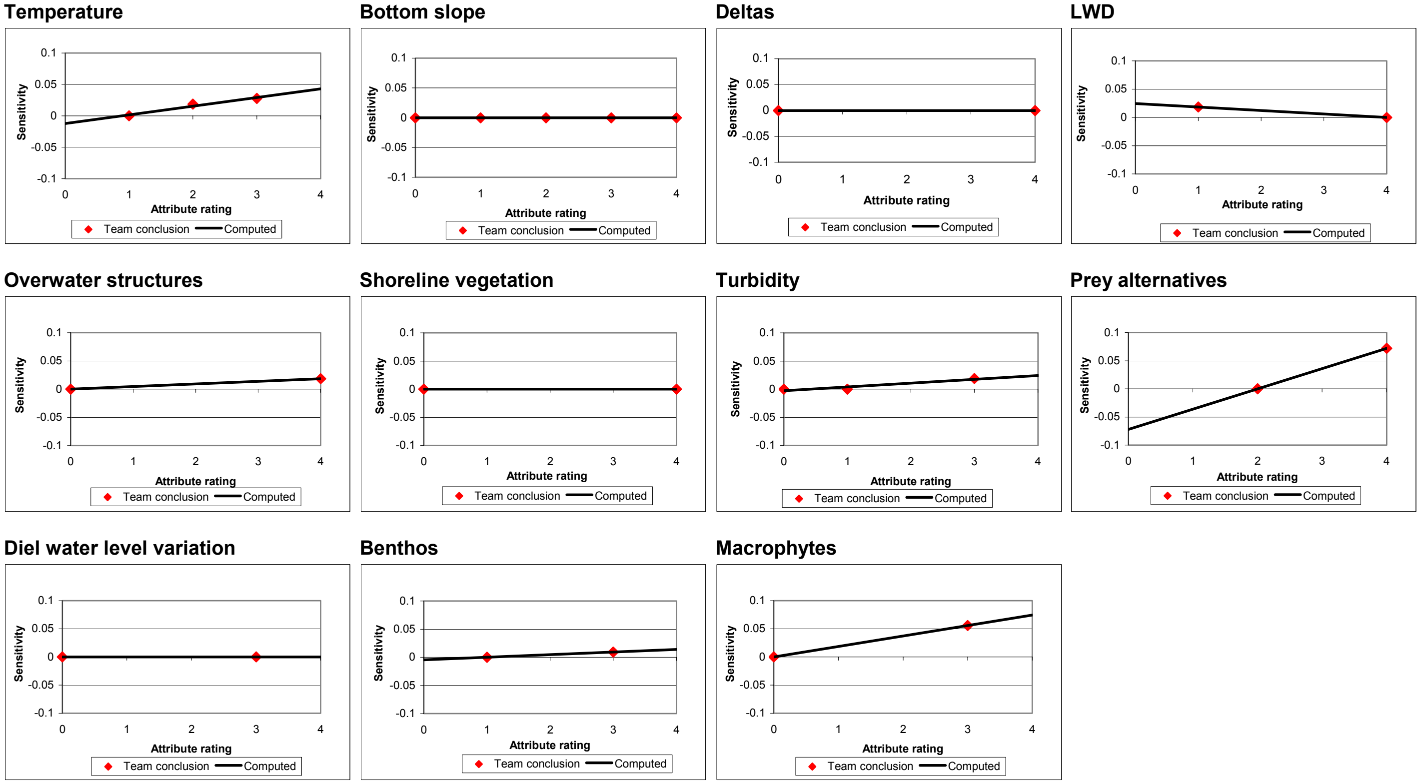
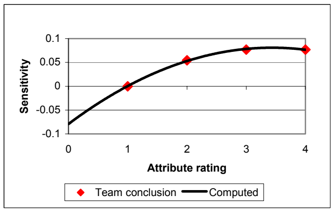


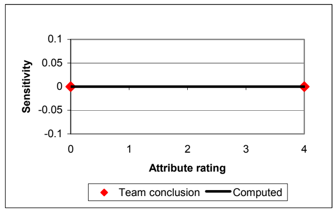
Figure C-34. Sensitivity curves for Crayfish in modifiers littoral.

Bass
Modifying effects (as multiplicative factors)
Effects associated with reference or standard conditions (effects assumed the same for all bank and substrate types)

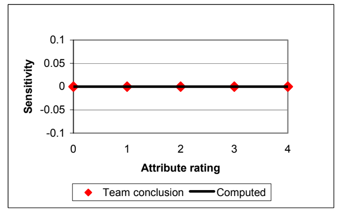
Temperature



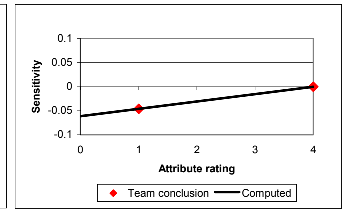
Bottom slope



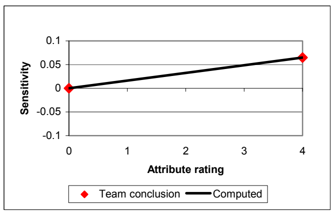
Deltas



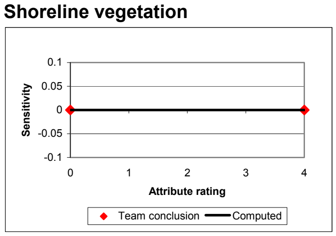
LWD



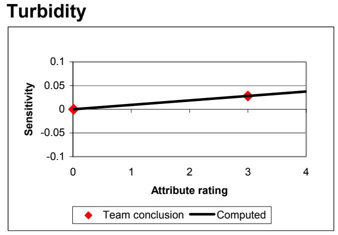
Overwater structures



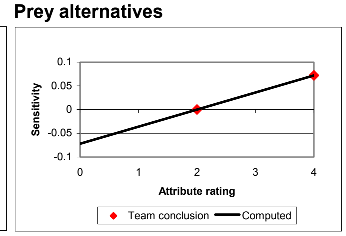
Shoreline vegetation



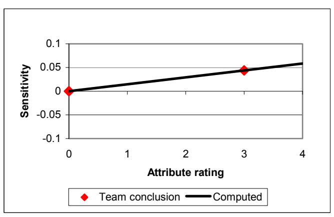
Turbidity



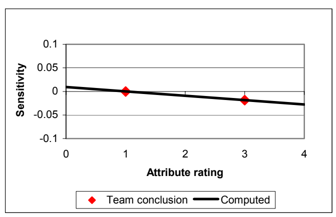
Prey alternatives



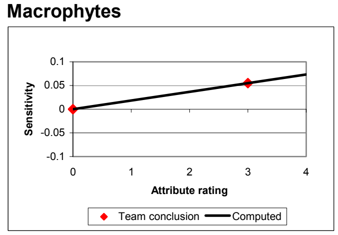
Diel water level variation



Benthos



Macrophytes



Figures C-3. Sensitivity curves for Bass in modifiers littoral.

Perch

Modifying effects (as multiplicative factors)

Effects associated with reference or standard conditions (effects assumed the same for all bank and substrate types)

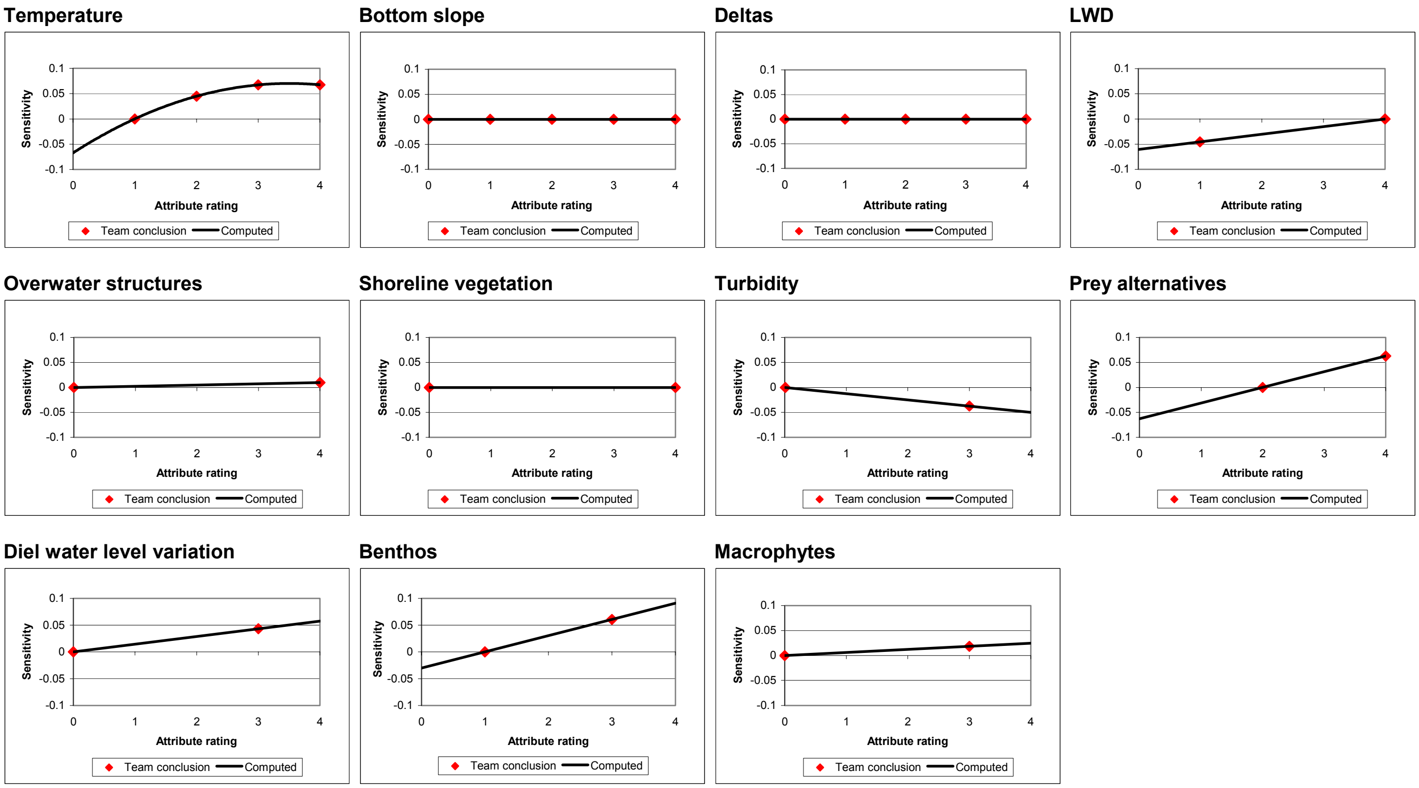


Figure C-36. Sensitivity curves for Perch in modifiers littoral.

Brown Bullhead

Modifying effects (as multiplicative factors)

Effects associated with reference or standard conditions (effects assumed the same for all bank and substrate types)

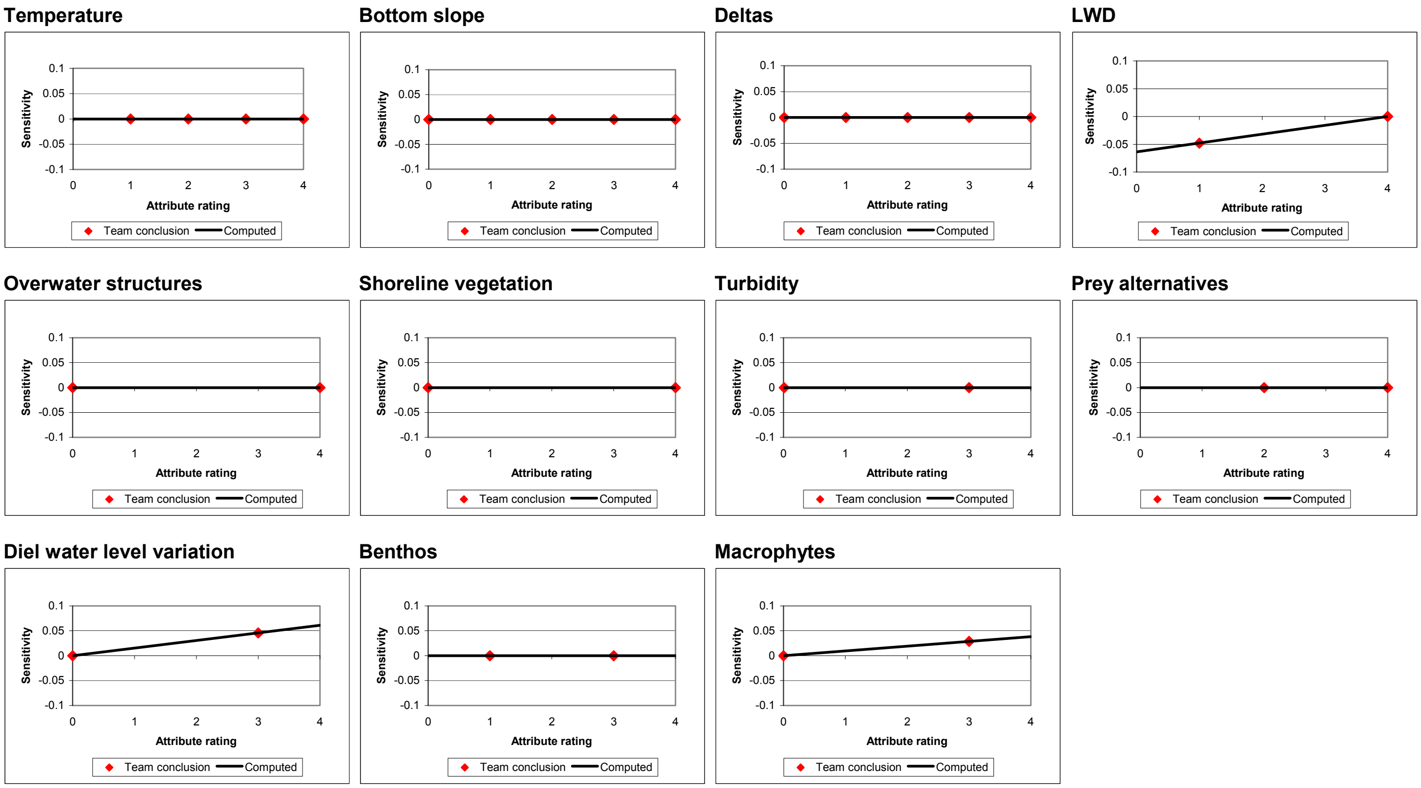
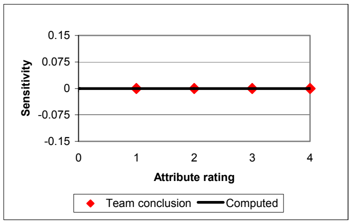


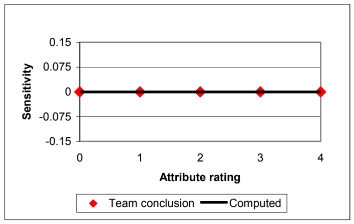
Figure C-37. Sensitivity curves for Brown bullhead in modifiers littoral.

Residual Coho
Modifying effects (as multiplicative factors)
Effects associated with reference or standard conditions (effects assumed the same for all bank and substrate types)

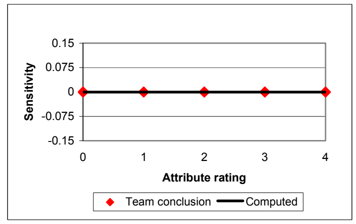
Temperature



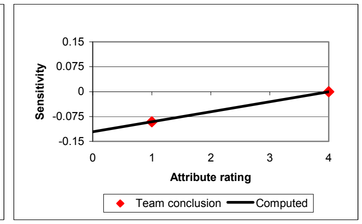
Bottom slope



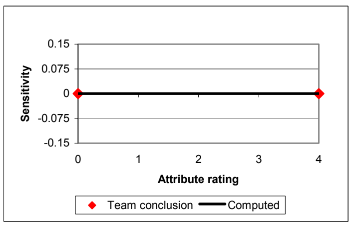
Deltas



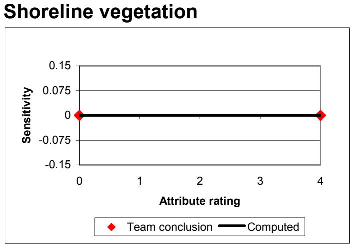
LWD



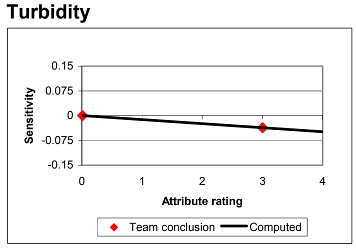
Overwater structures



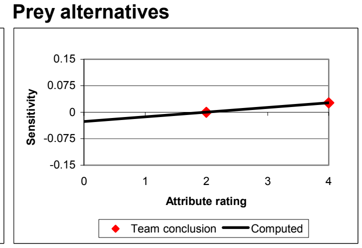
Shoreline vegetation



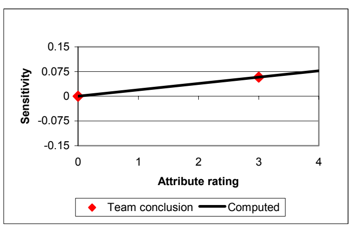
Turbidity



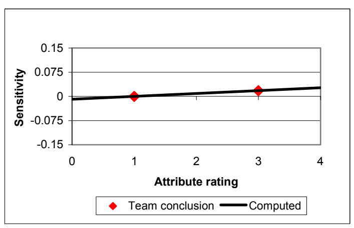
Prey alternatives



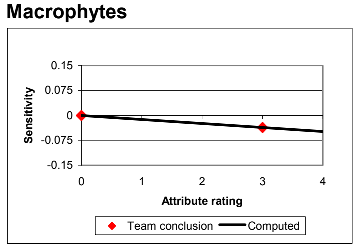
Diel water level variation



Benthos



Macrophytes

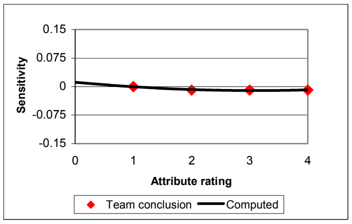


Figures C-3. Sensitivity curves for residual coho in modifiers littoral.

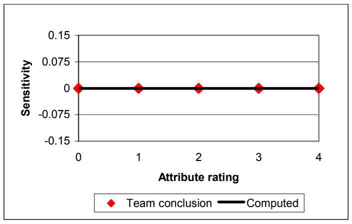
Hatchery Coho
Modifying effects (as multiplicative factors)

Effects associated with reference or standard conditions (effects assumed the same for all bank and substrate types)

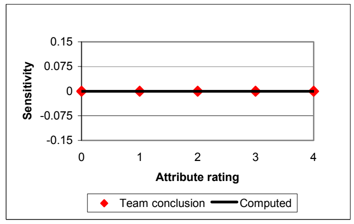
Temperature



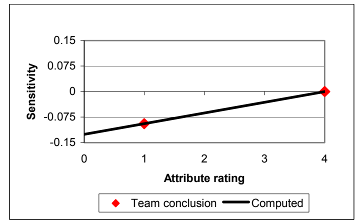
Bottom slope



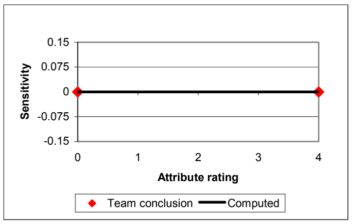
Deltas



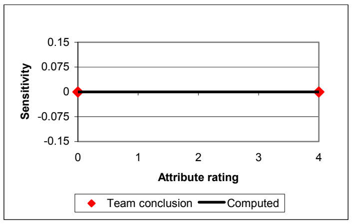
LWD



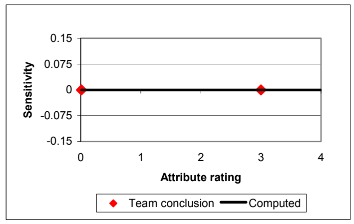
Overwater structures



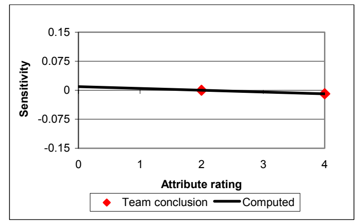
Shoreline vegetation



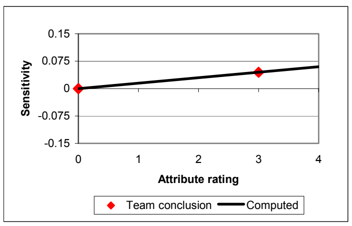
Turbidity



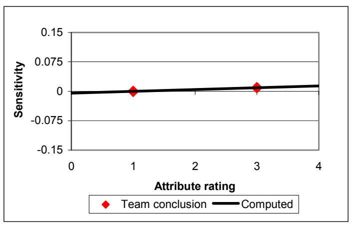
Prey alternatives



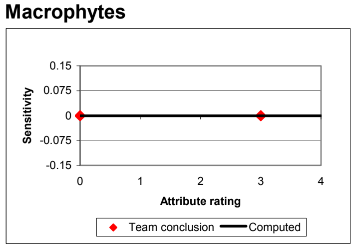
Diel water level variation



Benthos



Macrophytes



Figures C-3. Sensitivity curves for hatchery coho in modifiers littoral.

Grebes

Modifying effects (as multiplicative factors)

Effects associated with reference or standard conditions (effects assumed the same for all bank and substrate types)

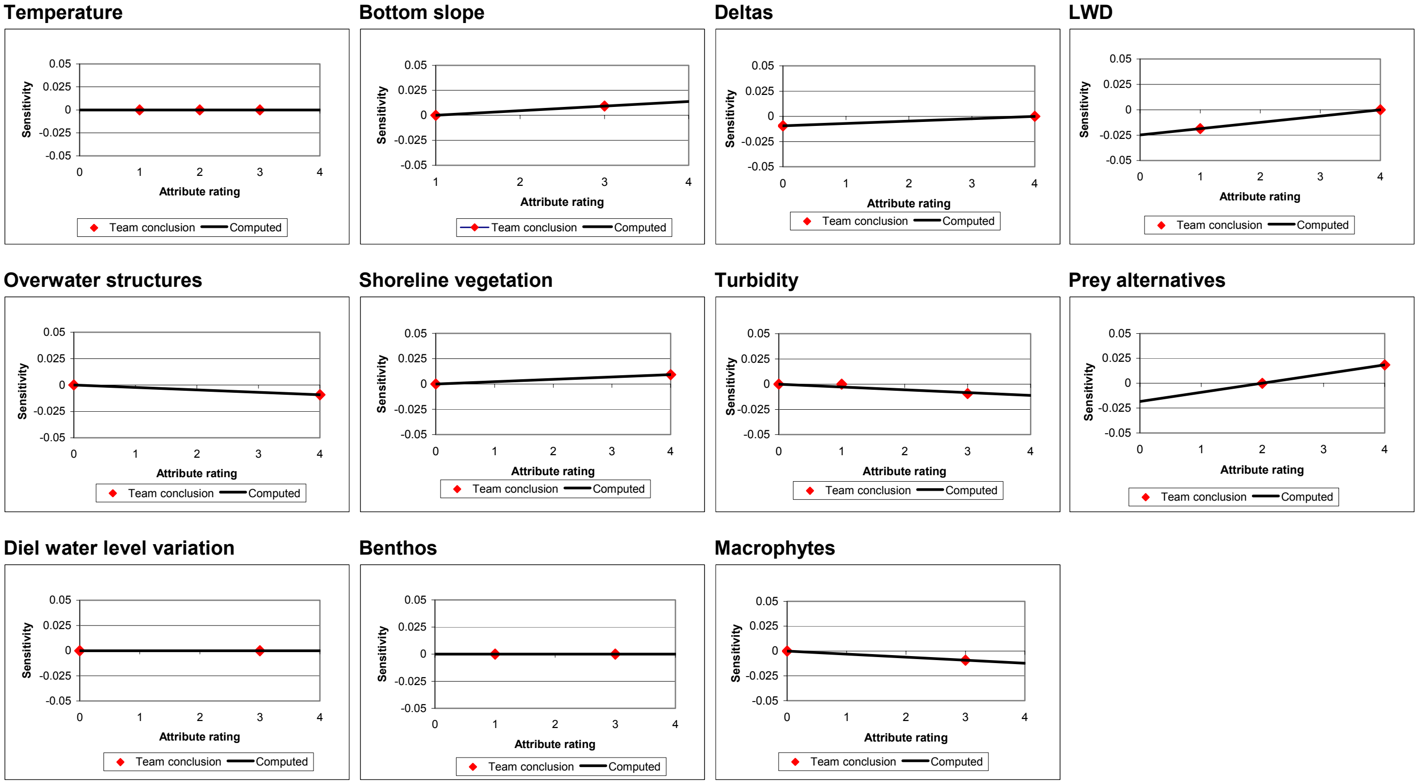


Figure C-40. Sensitivity curves for Grebes in modifiers littoral.

Cormorants
Modifying effects (as multiplicative factors)

Effects associated with reference or standard conditions (effects assumed the same for all bank and substrate types)

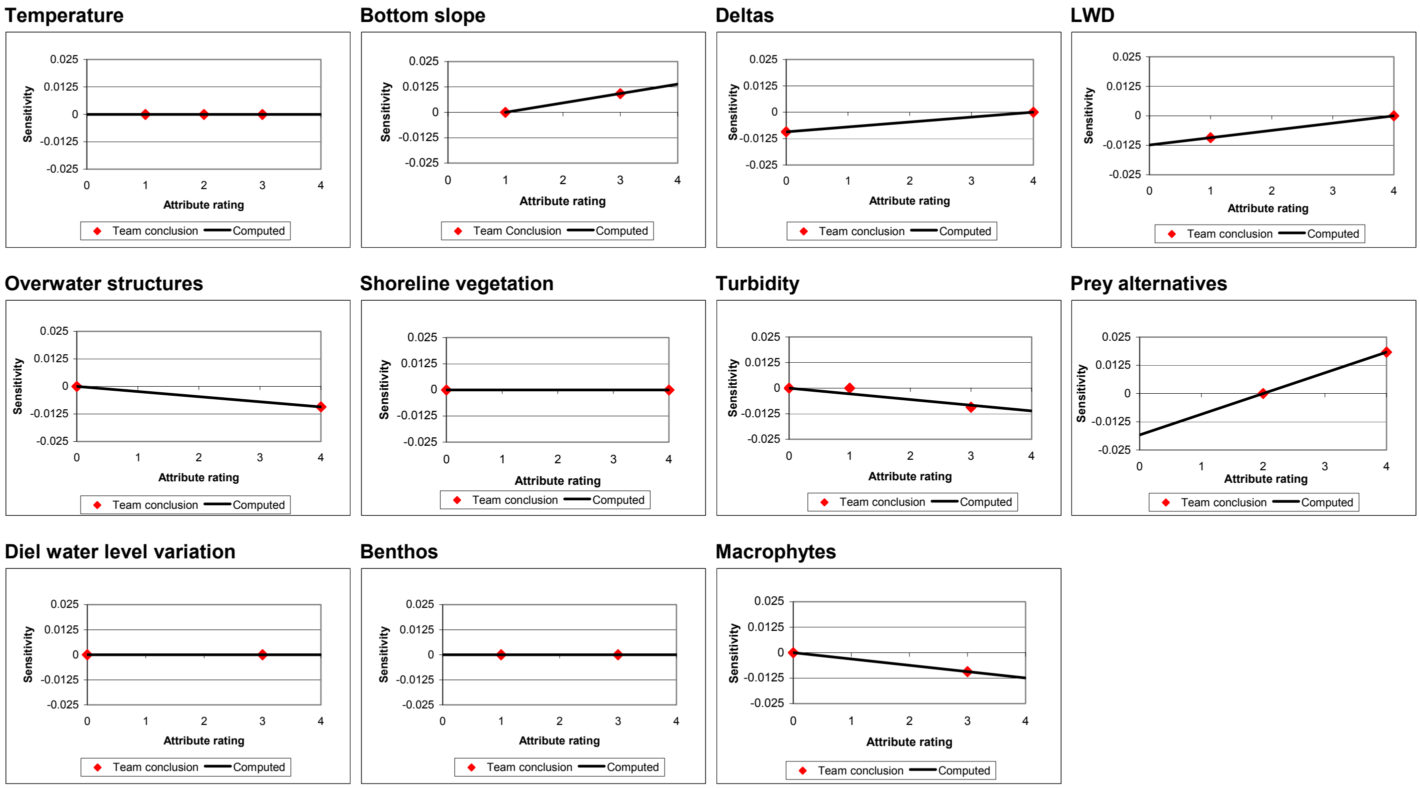


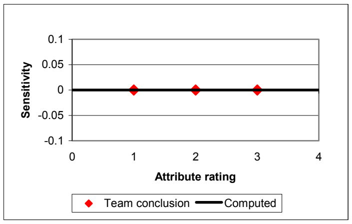
Figure C-41. Sensitivity curves for Cormorants in modifiers littoral.

Herons

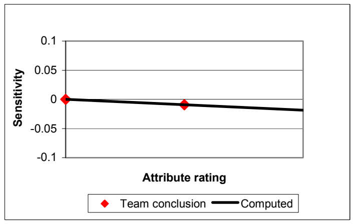
Modifying effects (as multiplicative factors)

Effects associated with reference or standard conditions (effects assumed the same for all bank and substrate types)

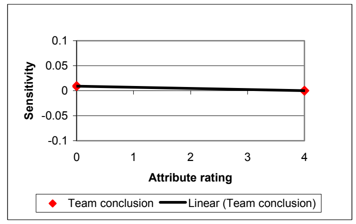
Temperature



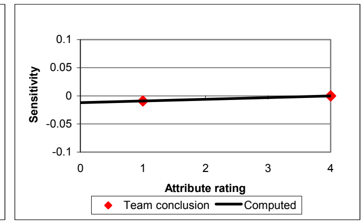
Bottom slope



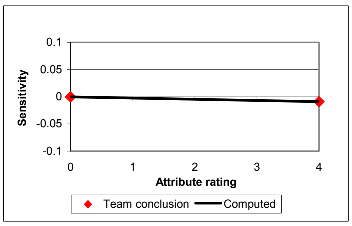
Deltas



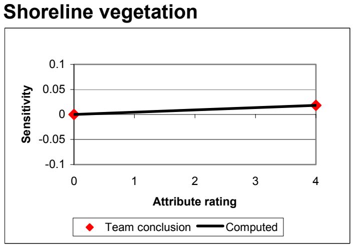
LWD



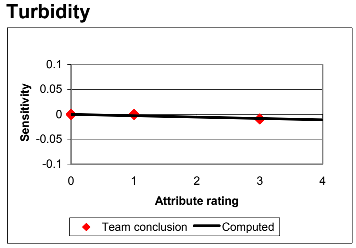
Overwater structures



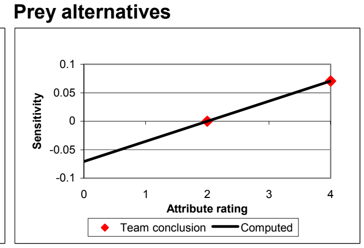
Shoreline vegetation



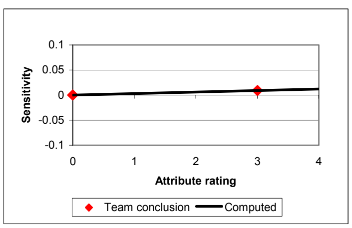
Turbidity



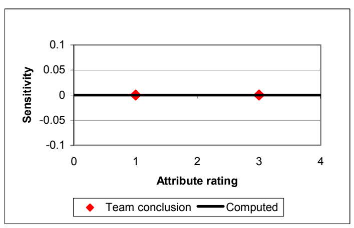
Prey alternatives



Diel water level variation



Benthos



Macrophytes

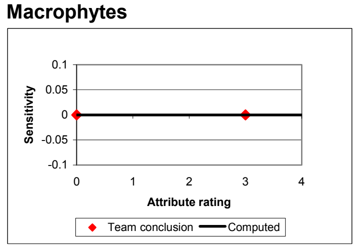


Figure C-42. Sensitivity curves for Herons in modifiers littoral.

Mergansers

Modifying effects (as multiplicative factors)

Effects associated with reference or standard conditions (effects assumed the same for all bank and substrate types)

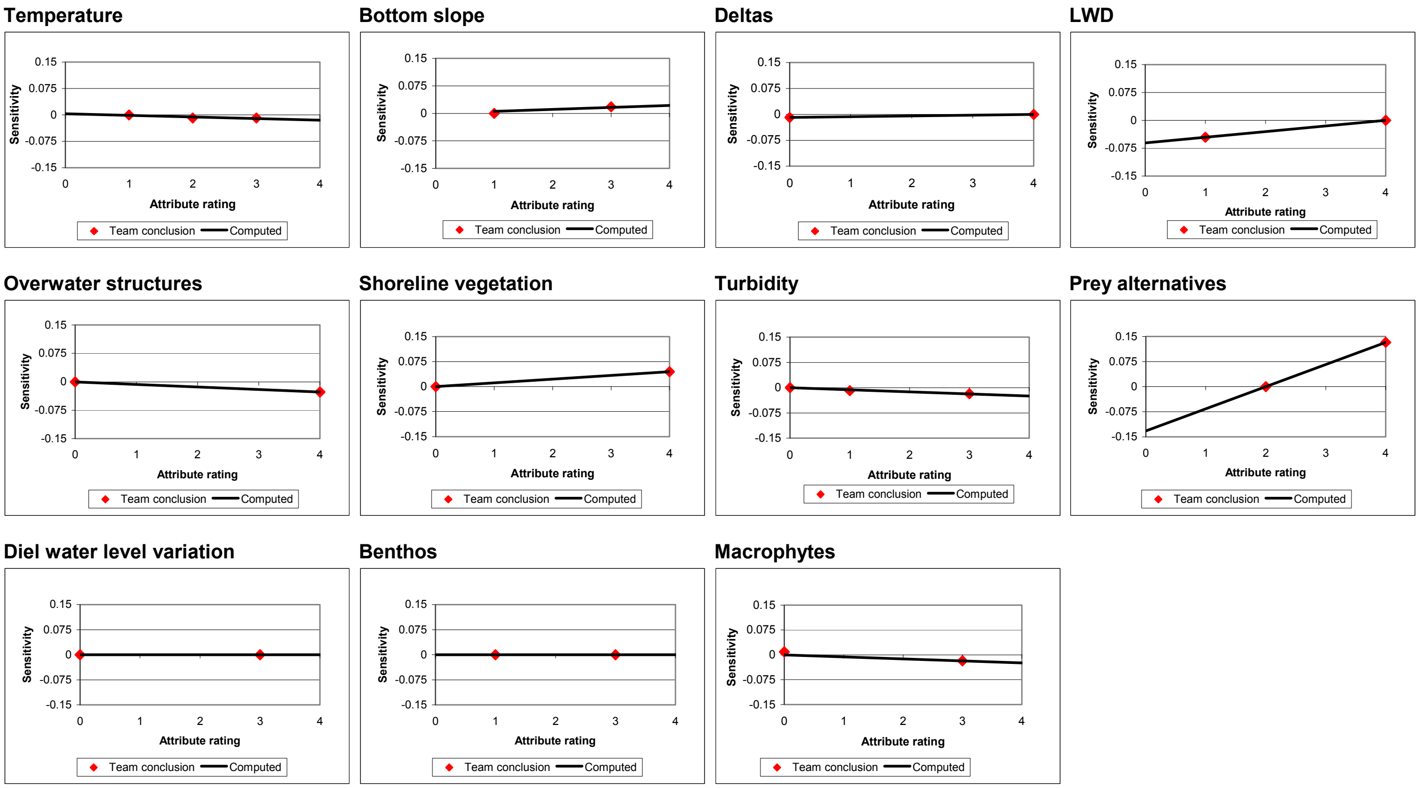


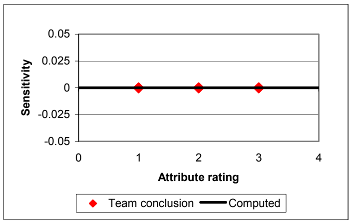
Figure C-43. Sensitivity curves for Mergansers in modifiers littoral.

Gulls

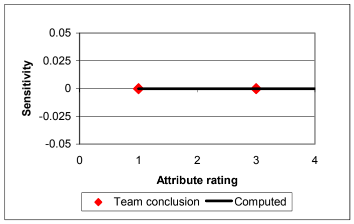
Modifying effects (as multiplicative factors)

Effects associated with reference or standard conditions (effects assumed the same for all bank and substrate types)

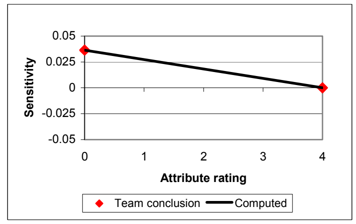
Temperature



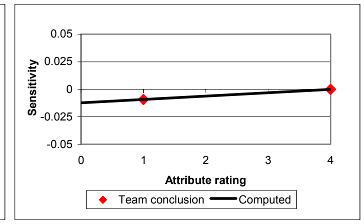
Bottom slope



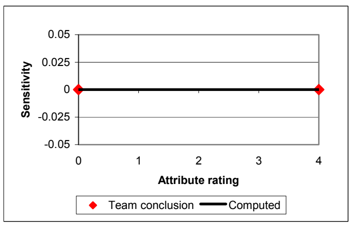
Deltas



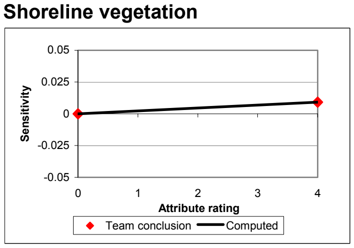
LWD



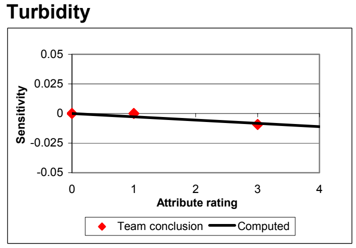
Overwater structures



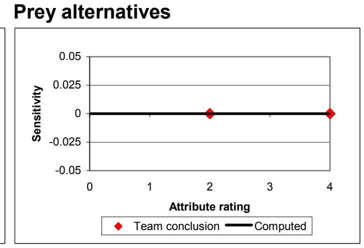
Shoreline vegetation



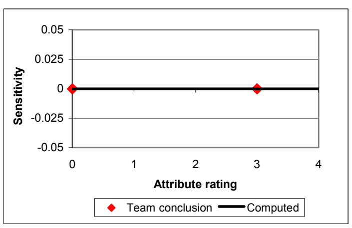
Turbidity



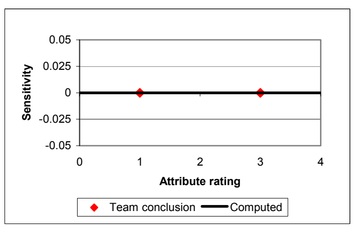
Prey alternatives



Diel water level variation



Benthos



Macrophytes

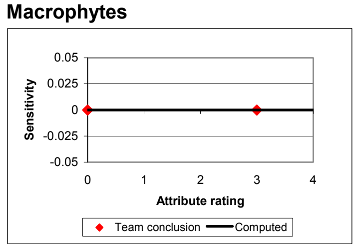


Figure C-44. Sensitivity curves for Gulls in modifiers littoral.

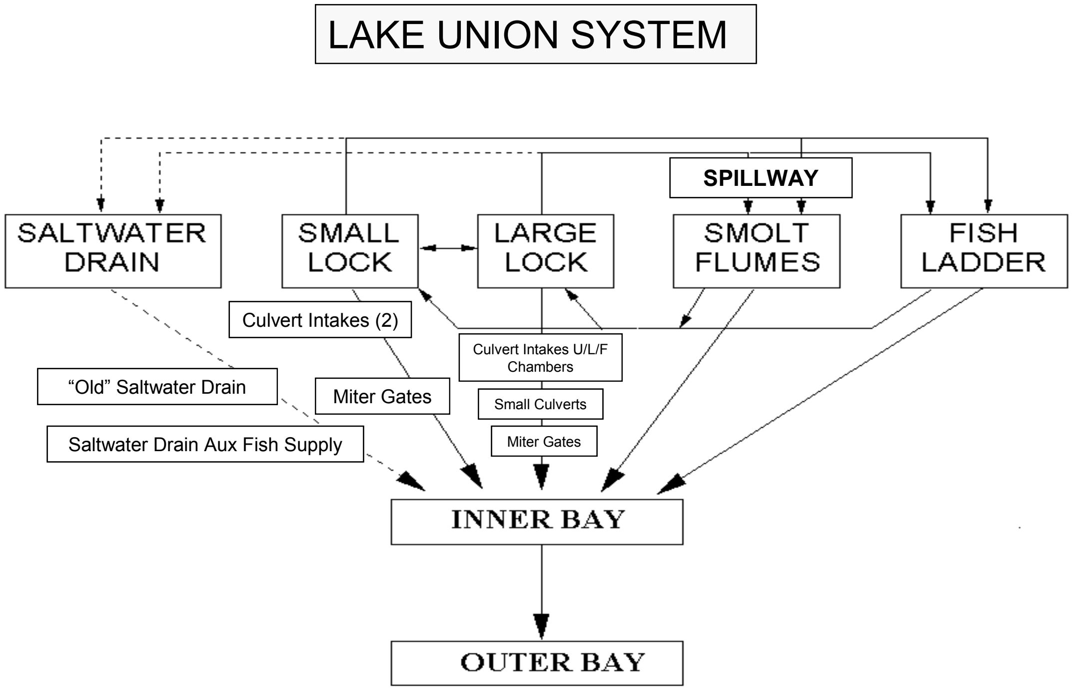
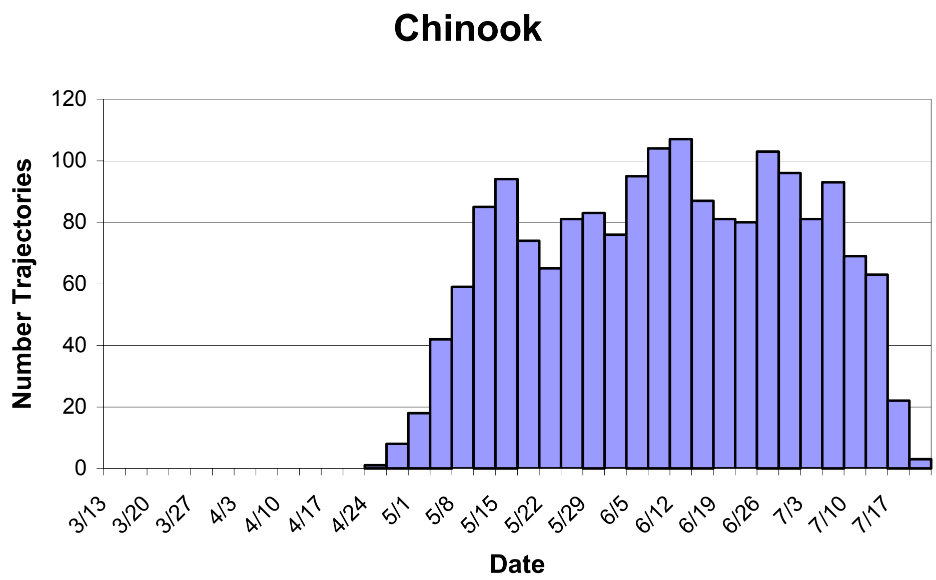


Figure C-45. Conceptual model of observed (solid lines) and possible (dashed lines) juvenile fish routes through the Ship Canal Locks.



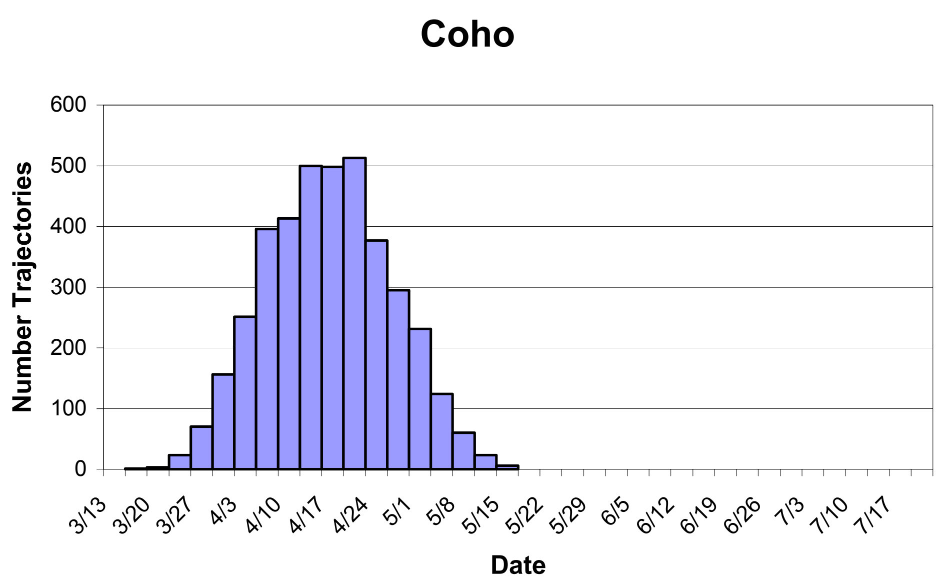


Figure C-46. Timing at the Hiram M. Chittenden Locks for a representative group of life history trajectories generated by the Habitat Assessment Model. The diversity of life history patterns modeled for Chinook resulted in a broader period of outmigration at the Locks.

Table C-3. Chinook and coho migration route (% fish using each route); High Water Yr. Last column shows overall survival across all routes for each week. Bold columns are calculated cells based on RFGE assumptions for the spillway flume and large lock filling culverts.

Month		Large Lock		Small Lock		Saltwater Drain		Spillway Flumes	Fish Ladder
		Filling Culverts	Miter Gates	Filling Culverts	Miter Gates	Old Drain	Saltwater - Fish Ladder		
March	02/26-03/04	95%	99%	95%	99%	100%	0%	99%	100%
	03/05-03/11	95%	99%	95%	99%	100%	0%	99%	100%
	03/12-03/18	95%	99%	95%	99%	100%	0%	99%	100%
	03/19-03/25	95%	99%	95%	99%	100%	0%	99%	100%
	03/26-04/01	95%	99%	95%	99%	100%	0%	99%	100%
April	04/02-04/08	95%	99%	95%	99%	100%	0%	99%	100%
	04/09-04/15	95%	99%	95%	99%	100%	0%	99%	100%
	04/16-04/22	95%	99%	95%	99%	100%	0%	99%	100%
	04/23-04/29	95%	99%	95%	99%	100%	0%	99%	100%
May	04/30-05/06	95%	99%	95%	99%	100%	0%	99%	100%
	05/07-05/13	95%	99%	95%	99%	100%	0%	99%	100%
	05/14-05/20	95%	99%	95%	99%	100%	0%	99%	100%
	05/21-05/27	95%	99%	95%	99%	100%	0%	99%	100%
	05/28-06/03	95%	99%	95%	99%	100%	0%	99%	100%
June	06/04-06/10	95%	99%	95%	99%	100%	0%	99%	100%
	06/11-06/17	95%	99%	95%	99%	100%	0%	99%	100%
	06/18-06/24	95%	99%	95%	99%	100%	0%	99%	100%
	06/25-07/01	95%	99%	95%	99%	100%	0%	99%	100%
July	07/02-07/08	95%	99%	95%	99%	100%	0%	99%	100%
	07/09-07/15	95%	99%	95%	99%	100%	0%	99%	100%
	07/16-07/22	94%	99%	94%	99%	100%	0%	99%	100%
	07/23-07/29	94%	99%	94%	99%	100%	0%	99%	100%
August	07/30-08/05	94%	99%	94%	99%	100%	0%	99%	100%
	08/06-08/12	93%	99%	93%	99%	100%	0%	99%	100%
	08/13-08/19	93%	99%	93%	99%	100%	0%	99%	100%
	08/20-08/26	93%	99%	93%	99%	100%	0%	99%	100%
	08/27-09/02	93%	99%	93%	99%	100%	0%	99%	100%

Table C-4. Chinook and coho migration route (% fish using each route); High Water Yr. Last column shows overall survival across all routes for each week. Bold columns are calculated cells based on RFGE assumptions for the spillway flume and large lock filling culverts.

Month	Week	Large Lock		Small Lock		Saltwater Drain		**Spillway Flumes**	Fish Ladder	Sum All Routes	RFGE		Calculated Survival All Routes
		Filling Culverts	Miter Gates	Filling Culverts	Miter Gates	Old Drain	Saltwater - Fish Ladder				Spillway Flumes	Filling Culverts	
March	02/26-03/04	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100%	95%	5%	99%
	03/05-03/11	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100%	95%	5%	99%
	03/12-03/18	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100%	95%	5%	99%
	03/19-03/25	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100%	95%	5%	99%
	03/26-04/01	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100%	95%	5%	99%
April	04/02-04/08	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100%	95%	5%	99%
	04/09-04/15	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100%	95%	5%	99%
	04/16-04/22	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100%	95%	5%	99%
	04/23-04/29	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100%	95%	5%	99%
May	04/30-05/06	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100%	95%	5%	99%
	05/07-05/13	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100%	95%	5%	99%
	05/14-05/20	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100%	95%	5%	99%
	05/21-05/27	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100%	95%	5%	99%
	05/28-06/03	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100%	95%	5%	99%
June	06/04-06/10	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100%	95%	5%	99%
	06/11-06/17	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100%	95%	5%	99%
	06/18-06/24	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100%	95%	5%	99%
	06/25-07/01	**4.6%**	40.0%	1.0%	2.0%	1.0%	1.0%	**50.0%**	0.5%	100%	90%	10%	98%
July	07/02-07/08	**4.7%**	66.0%	1.0%	3.0%	1.0%	1.0%	**22.8%**	0.5%	100%	80%	20%	98%
	07/09-07/15	**5.5%**	75.0%	1.0%	3.0%	0.5%	0.5%	**14.0%**	0.5%	100%	70%	30%	98%
	07/16-07/22	**5.0%**	84.0%	1.0%	3.0%	0.5%	0.5%	**5.5%**	0.5%	100%	50%	50%	98%
	07/23-07/29	**2.4%**	88.0%	1.0%	3.0%	2.0%	2.0%	**1.1%**	0.5%	100%	20%	80%	97%
August	07/30-08/05	**3.0%**	88.0%	1.0%	3.0%	2.0%	2.0%	**0.5%**	0.5%	100%	10%	90%	97%
	08/06-08/12	**3.2%**	88.0%	1.0%	3.0%	2.0%	2.0%	**0.3%**	0.5%	100%	5%	95%	97%
	08/13-08/19	**0.5%**	90.0%	1.0%	4.0%	2.0%	2.0%	**0.0%**	0.5%	100%	0%	100%	97%
	08/20-08/26	**0.5%**	90.0%	1.0%	4.0%	2.0%	2.0%	**0.0%**	0.5%	100%	0%	100%	97%
	08/27-09/02	**0.5%**	90.0%	1.0%	4.0%	2.0%	2.0%	**0.0%**	0.5%	100%	0%	100%	97%

Table C-5. Chinook and coho migration route (% fish using each route); Normal Water Yr. Last column shows overall survival across all routes for each week. Bold columns are calculated cells based on RFGE assumptions for the spillway flume and large lock filling culverts.

Month	Week	Large Lock		Small Lock		Saltwater Drain		Spillway Flumes	Fish Ladder	Sum all Routes	RFGE		Calculated Survival all Routes
		Filling Culverts	Miter Gates	Filling Culverts	Miter Gates	Old Drain	Saltwater - Fish Ladder				Spillway Flumes	Filling Culverts	
March	02/26-03/04	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100.0%	95.0%	5.0%	98.8%
	03/05-03/11	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100.0%	95.0%	5.0%	98.8%
	03/12-03/18	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100.0%	95.0%	5.0%	98.8%
	03/19-03/25	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100.0%	95.0%	5.0%	98.8%
	03/26-04/01	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100.0%	95.0%	5.0%	98.8%
April	04/02-04/08	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100.0%	95.0%	5.0%	98.8%
	04/09-04/15	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100.0%	95.0%	5.0%	98.8%
	04/16-04/22	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100.0%	95.0%	5.0%	98.8%
	04/23-04/29	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100.0%	95.0%	5.0%	98.8%
May	04/30-05/06	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100.0%	95.0%	5.0%	98.8%
	05/07-05/13	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100.0%	95.0%	5.0%	98.8%
	05/14-05/20	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100.0%	95.0%	5.0%	98.8%
	05/21-05/27	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100.0%	95.0%	5.0%	98.8%
	05/28-06/03	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100.0%	95.0%	5.0%	98.8%
June	06/04-06/10	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100.0%	95.0%	5.0%	98.8%
	06/11-06/17	**4.6%**	40.0%	1.0%	2.0%	1.0%	1.0%	**50.0%**	0.5%	100.0%	90.0%	10.0%	97.8%
	06/18-06/24	**4.3%**	60.0%	1.0%	2.0%	1.0%	1.0%	**30.2%**	0.5%	100.0%	85.0%	15.0%	97.8%
	06/25-07/01	**4.9%**	66.0%	1.0%	2.0%	1.0%	1.0%	**23.6%**	0.5%	100.0%	80.0%	20.0%	97.8%
July	07/02-07/08	**3.9%**	75.0%	1.0%	3.0%	1.0%	1.0%	**14.6%**	0.5%	100.0%	75.0%	25.0%	97.8%
	07/09-07/15	**3.9%**	75.0%	1.0%	3.0%	1.0%	1.0%	**14.6%**	0.5%	100.0%	75.0%	25.0%	97.8%
	07/16-07/22	**0.5%**	90.0%	1.0%	4.0%	2.0%	2.0%	**0.0%**	0.5%	100.0%	0.0%	100.0%	97.0%
	07/23-07/29	**0.5%**	90.0%	1.0%	4.0%	2.0%	2.0%	**0.0%**	0.5%	100.0%	0.0%	100.0%	97.0%
August	07/30-08/05	**0.5%**	90.0%	1.0%	4.0%	2.0%	2.0%	**0.0%**	0.5%	100.0%	0.0%	100.0%	97.0%
	08/06-08/12	**0.5%**	90.0%	1.0%	4.0%	2.0%	2.0%	**0.0%**	0.5%	100.0%	0.0%	100.0%	97.0%
	08/13-08/19	**0.5%**	90.0%	1.0%	4.0%	2.0%	2.0%	**0.0%**	0.5%	100.0%	0.0%	100.0%	97.0%
	08/20-08/26	**0.5%**	90.0%	1.0%	4.0%	2.0%	2.0%	**0.0%**	0.5%	100.0%	0.0%	100.0%	97.0%
	08/27-09/02	**0.5%**	90.0%	1.0%	4.0%	2.0%	2.0%	**0.0%**	0.5%	100.0%	0.0%	100.0%	97.0%

Table C-6. Chinook and coho migration route (% fish using each route); Low Water Yr. Last column shows overall survival across all routes for each week. Bold columns are calculated cells based on RFGE assumptions for the spillway flume and large lock filling culverts.

Month	Week	Large Lock		Small Lock		Saltwater Drain		**Spillway Flumes**	Fish Ladder	Sum all Routes	RFGE		Calculated Survival all Routes
		Filling Culverts	Miter Gates	Filling Culverts	Miter Gates	Old Drain	Saltwater - Fish Ladder				Spillway Flumes	Filling Culverts	
March	02/26-03/04	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100.0%	95.0%	5.0%	98.8%
	03/05-03/11	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100.0%	95.0%	5.0%	98.8%
	03/12-03/18	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100.0%	95.0%	5.0%	98.8%
	03/19-03/25	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100.0%	95.0%	5.0%	98.8%
	03/26-04/01	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100.0%	95.0%	5.0%	98.8%
April	04/02-04/08	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100.0%	95.0%	5.0%	98.8%
	04/09-04/15	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100.0%	95.0%	5.0%	98.8%
	04/16-04/22	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100.0%	95.0%	5.0%	98.8%
	04/23-04/29	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100.0%	95.0%	5.0%	98.8%
May	04/30-05/06	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100.0%	95.0%	5.0%	98.8%
	05/07-05/13	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100.0%	95.0%	5.0%	98.8%
	05/14-05/20	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100.0%	95.0%	5.0%	98.8%
	05/21-05/27	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100.0%	95.0%	5.0%	98.8%
	05/28-06/03	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100.0%	95.0%	5.0%	98.8%
June	06/04-06/10	**5.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	**94.5%**	0.5%	100.0%	95.0%	5.0%	98.8%
	06/11-06/17	**4.6%**	40.0%	1.0%	2.0%	1.0%	1.0%	**50.0%**	0.5%	100.0%	90.0%	10.0%	97.8%
	06/18-06/24	**0.5%**	90.0%	1.0%	4.0%	2.0%	2.0%	**0.0%**	0.5%	100.0%	0.0%	100.0%	97.0%
	06/25-07/01	**0.5%**	90.0%	1.0%	4.0%	2.0%	2.0%	**0.0%**	0.5%	100.0%	0.0%	100.0%	97.0%
July	07/02-07/08	**0.5%**	90.0%	1.0%	4.0%	2.0%	2.0%	**0.0%**	0.5%	100.0%	0.0%	100.0%	97.0%
	07/09-07/15	**0.5%**	90.0%	1.0%	4.0%	2.0%	2.0%	**0.0%**	0.5%	100.0%	0.0%	100.0%	97.0%
	07/16-07/22	**0.5%**	90.0%	1.0%	4.0%	2.0%	2.0%	**0.0%**	0.5%	100.0%	0.0%	100.0%	97.0%
	07/23-07/29	**0.5%**	90.0%	1.0%	4.0%	2.0%	2.0%	**0.0%**	0.5%	100.0%	0.0%	100.0%	97.0%
August	07/30-08/05	**0.5%**	90.0%	1.0%	4.0%	2.0%	2.0%	**0.0%**	0.5%	100.0%	0.0%	100.0%	97.0%
	08/06-08/12	**0.5%**	90.0%	1.0%	4.0%	2.0%	2.0%	**0.0%**	0.5%	100.0%	0.0%	100.0%	97.0%
	08/13-08/19	**0.5%**	90.0%	1.0%	4.0%	2.0%	2.0%	**0.0%**	0.5%	100.0%	0.0%	100.0%	97.0%
	08/20-08/26	**0.5%**	90.0%	1.0%	4.0%	2.0%	2.0%	**0.0%**	0.5%	100.0%	0.0%	100.0%	97.0%
	08/27-09/02	**0.5%**	90.0%	1.0%	4.0%	2.0%	2.0%	**0.0%**	0.5%	100.0%	0.0%	100.0%	97.0%

Table C-7. Level of Proof codes used to characterize data quality for survival and % fish utilization by route at the Locks.

Level	Proof
1	Throughly established, generally accepted, good peer-reviewed empirical evidence in its favor
2	Strong weight of evidence in support but not fully conclusive
3	Theoretical support with some evidence from experiments or observations
4	Speculative, little emperical support

Table C-8. Level of proof ratings for survival assumption by migration route and % fish utilizing each route.

Survival Assumptions

	Large Lock		Small Lock		Saltwater Drain			
Time Period	Filling Culverts	Miter Gates	Filling Culverts	Miter Gates	Old Drain	Saltwater - Fish Ladder	Spillway Flumes	Fish Ladder
March - June	2	3	3-4	3-4	4	4	3-4	3-4
July - August	4	4	3-4	3-4	4	4	3-4	3-4

Juvenile Migration Route

	Large Lock		Small Lock		Saltwater Drain			
Time Period	Filling Culverts	Miter Gates	Filling Culverts	Miter Gates	Old Drain	Saltwater - Fish Ladder	Spillway Flumes	Fish Ladder
March - June	2-3	3-4	3-4	3-4	4	4	3-4	3-4
July - August	4	4	4	4	4	4	3-4	3-4

Table C-9. Tidal Habitat Model (WRIA 8 EDT modification). Shaded questions address long-term process features and were excluded from the analysis. Question 35 was added to address the input of Dahnia to the Lake Washington estuary from lakes.

Date	**Surveyors**	**On Site or Off Site? Circle**	M-migration, O-osmoregulatory, P-predator avoidance					
AU #	**Supplement w/Aerials?**	**Date and Type?**	Y/N	CHIN	COHO	Functions Addressed	Comments
Hydrology						F, M, O	
1	AU has vernal or perennial freshwater stream or spring			3	3	F, O	
2a	AU is depositional (slow currents, low wave action) over 25% of littoral area			2	2	F	
2b	AU is depositional (slow currents, low wave action) over 50% of littoral area			3	3	F	
3	AU has refuge from high velocities (e.g., during max. ebb)			3	3	M, P	
4a	AU contains a natural tidal channel wetted at MLLW			X1.5	X1.3	F, P	
4b	AU contains tidal channel wetted at MSL (i.e., shallow drainage)			2	2	F, P	
5	Tidal channel is dendritic or highly sinuous			3	3	F, P	
Water Quality							
6a	Oligohaline to Mesohaline (sal. variable: often 0.5 to 5 ppt, but can range to 18 ppt)			3	3	F, O	
6b	Polyhaline (sal. typically 18 to 30 ppt)			1	1	F, O	
7a	Temp/DO meet criteria for salmonid health during major use periods			2	2	H	
7b	Temp/DO meet criteria for salmonid health at all times			3	3	H	
Physical Features							
	Vascular plant/mud (or sand) flat boundary (vegetated/unvegetated boundary)						
	Shoreline complexity						
8a	Ratio of length of MHHW boundary to width at MLLW >3 (include islands)			3	3	F, P	
8b	Ratio of length of MHHW boundary to width at MLLW 1.2 to 3 (include islands)			2	2	F, P	
8c	Ratio of length of MHHW boundary to width at MLLW <1.2 (include islands)			1	1	F, P	
Exposure							
9	AU is sheltered from waves			2	2	F	

Date	Surveyors	On Site or Off Site? Circle	M-migration, O-osmoregulatory, P-predator avoidance				
AU #	Supplement w/Aerials?	Date and Type?	Y/N	CHIN	COHO	Functions Addressed	Comments
Slope							
10a	Slope of substrate in littoral zone >10h:1v (i.e., low gradient)			3	3	F, P	
10b	Slope of substrate in littoral zone <10h:1v but >5h:1v (i.e., moderate)			2	2	F, P	
10c	Slope of substrate in littoral zone <5h:1v but >2h:1v (i.e., steeper)			1	1	F, P	
Range of Depths							
11a	>10% of AU is littoral (MHHW to -10 ft; use OHW if marsh veg. above MHHW)			1	1	F, P	
11b	>25% of AU is littoral (MHHW to -10 ft; use OHW where vegetation indicates)			2	2	F, P	
11c	>50% of AU is littoral (MHHW to -10 ft; use OHW where vegetation indicates)			3	3	F, P	
Sediments (surficial only)							
12	Substrate in littoral zone - silty sand >25% of area			1	1	F	
13	Substrate in littoral zone - mud or mixed fine 25 - 50% of area			2	2	F	
14	Substrate in littoral zone - mud or mixed fine >50% of area			3	3	F	
15	Upper intertidal zone contains potential forage fish spawning habitat			3	3	F	Long term process question
Vegetated Edge							
Below OHW							
16a	Buffer: marsh edge >10 ft wide over 50% of shoreline			3	3	F, P	
16b	Marsh edge >5 ft wide over 50% of shoreline; or >10 ft wide over 25-50% of shoreline			2	2	F, P	
16c	Marsh edge exists but <5 ft wide, or less than 25% (but >5%) of shoreline			1	1	F, P	
16d	Marsh of native species occupies more than 25% of total AU			X 2	X 2	F	
Above OHW (riparian zone)							
17a	Riparian scrub-shrub and/or forested >25 ft wide over 10 to 24% of shoreline			1	1	F, P	
17b	Riparian scrub-shrub and/or forested >25 ft wide over 25 to 50% of shoreline			2	2	F, P	
17c	Riparian scrub-shrub and/or forested >25 ft over 50% of shoreline			3	3	F, P	

Date	**Surveyors** **On Site or Off Site? Circle**	M-migration, O-osmoregulatory, P-predator avoidance				
AU #	**Supplement w/Aerials?** **Date and Type?**	Y/N	CHIN	COHO	Functions Addressed	Comments
18	Riparian vegetation is dominated by native species		1	1	F	
19	Riparian zone provides significant source of LWD recruitment		X1.5	X1.5	F, P	Long term process question
Landscape						
Special Habitat Features						
	LWD Density (LWD must be in the IT zone below MHHW)					
21a	1.0 piece/channel width, /30 m of shoreline, or /100 m² of AU whichever is greater		3	3	P	
21b	0.5 piece/channel width, /30 m of shoreline, or /100 m² of AU whichever is greater		2	2	P	
21c	0.2 piece/channel width, /30 m of shoreline, or /100 m² of AU whichever is greater		1	1	P	
Submerged Vegetation (note provisions with regard to impacts to macrovegetation)						
22	Algal cover over 10% of littoral area (during springtime)		1	1	F, P	
23a	Eelgrass or kelp (laminarians) is present along 5 - 10% of low tide line of AU		1	1	F, P	
23b	Eelgrass or kelp (laminarians) is present along 10 - 25% of low tide line of AU		2	2	F, P	
23c	Eelgrass is or kelp (laminarians) present along more than 25% of low tide line of AU		3	3	F, P	
23d	Eelgrass or kelp (laminarians) occupies more than 25% of total area of AU		X 2	X 2	F, P	
24	Do functioning feeder bluffs provide a significant source of sediment to the AU?		X 2	X 2	F	Long term process question
35		X 2	X 2	F		Applicable to locks area only
Stressors						
25a	Immigration/emigration restricted 25 to 50% of the time		X 0.8	X 0.8	M	
25b	Immigration/emigration restricted 50 to 75% of the time		X 0.5	X 0.5	M	
25c	Immigration/emigration restricted 75 to 90% of the time		X 0.3	X 0.3	M	
29a	Sediment chemical contam. (exceeds applicable threshold over more than 25% of AU)		X 0.8	X 0.8	F, H	
29b	Sediment chemical contam. present (>CSL over more than 25% of AU)		X 0.6	X 0.6	F, H	
30a	Riprap or vertical bulkheads extend below MHHW for 10 - 50% of shore		X 0.8	X 0.9	P,M,F	

Date	**Surveyors**	**On Site or Off Site? Circle**	M-migration, O-osmoregulatory, P-predator avoidance				
AU #	**Supplement w/Aerials?**	**Date and Type?**	Y/N	CHIN	COHO	Functions Addressed	Comments
30b	Riprap or vertical bulkheads extend below MHHW along >50% of shore			X 0.7	X 0.8	P,M,F	
31	Majority of riprapped or bulkheaded shoreline extends below MSL (+6 ft MLLW)			X 0.8	X 0.9	P,M,F	
32a	Finger pier or dock >8 ft wide			X 0.9	–	P	
32b	Two or more finger piers or docks >8 ft wide; or single pier or dock >25 ft wide			X 0.8	X 0.9	P	
33a	Overwater structures cover 10 to 30% of littoral area in AU			X 0.9	–	P,M,F	
33b	Overwater structures cover 30 to 50% of littoral area in AU			X 0.8	X 0.9	P,M,F	
33c	Overwater structures cover 50 to 75% of littoral area in AU			X 0.7	X 0.8	P,M,F	
33d	Overwater structures cover >75% of littoral area in AU			X 0.6	X 0.7	P,M,F	
34	Littoral benthic habitat routinely disturbed by prop wash, chronic oil spills, or dredging			X 0.9	X 0.9	H, F	

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Table C-10. Nearshore Reaches (average scores rounded to nearest integer).

		0 Age Transient Chinook				1 Age Coho Smolts and 1 Age chinook			
		Current Condition		Template Condition		Current Condition		Template Condition	
Ecological Management Unit	Description	THM	Relative Surv	THM	Relative Surv	THM	Relative Surv	THM	Relative Surv
EMU 8	Elliot Point to Picnic Point	12.0	0.64	45.0	0.96	15.0	0.74	44.0	0.94
EMU 9	Picnic Point to Edwards Point	22.0	0.79	47.0	0.96	26.0	0.86	45.0	0.97
EMU 10A	Edwards Point to Meadow Point	16.0	0.71	44.0	0.93	19.0	0.80	43.0	0.94
EMU 10B	Meadow Point to Shilshole	9.0	0.57	31.0	0.86	11.0	0.69	31.0	0.89
EMU 12	Shilshole to West Point	13.0	0.64	44.0	0.93	14.0	0.75	44.0	0.94

Table C-11. Estuarine Reaches (average scores are rounded to nearest integer).

			0 Age Transient Chinook				1 Age Coho Smolts and 1 Age chinook			
			Current Condition		Template Condition		Current Condition		Template Condition	
Estuarine Reach	Description	AU #	THM	Relative Surv	THM	Relative Surv	THM	Relative Surv	THM	Relative Surv
Lake Washington Ship Canal	Face of Ballard locks to Shilshole	11.01 - 11.08	15.0	0.61	72.0	0.93	19.0	0.69	68.0	0.94
Piper Creek	Pipers Cr estuary and adjacent nearshore	10.12	34.0	0.71	78.0	0.96	33.0	0.77	68.0	0.94
Shellberger Creek	Shellberger Cr estuary, marsh and adjacent nearshore	9.14/9.15	23.0	0.64	101.0	1.00	22.0	0.71	88.0	1.00
Shell Creek	Shell Cr estuary and adjacent nearshore	9.08	34.0	0.71	78.0	0.96	38.0	0.80	68.0	0.94
Perrinville Creek	Perrinville Creek estuary and adjacent nearshore	9.06	12.0	0.57	78.0	0.96	16.0	0.69	68.0	0.94
Lund's Gulch Creek	Lund's Gulch Cr estuary and adjacent nearshore	9.04	26.0	0.68	78.0	0.96	26.0	0.74	68.0	0.94
Norma Creek	Norma Creek Estuary and adjacent nearshore	9.02	23.0	0.64	78.0	0.96	33.0	0.77	68.0	0.94
Picnic Pt Creek	Picnic Pt Cr estuary and adjacent nearshore	8.09	22.0	0.64	78.0	0.96	25.0	0.74	68.0	0.94
Big Gulch Creek	Big Gulch Cr estuary and adjacent nearshore	8.05	13.0	0.57	78.0	0.96	17.0	0.69	68.0	0.94

Table C-12. Assignment of Relative Survival (Productivity) values to THM scores. These are based on an assumption about the distribution of the THM score for each juvenile life stage, then interpolated between all intermediate scores with a relative survival of 1.0 for THM scores >85 for estuarine areas and >50 for nearshore units.

As Applied to Estuarine Assessment units

Transient rear (0 age chinook)		Age-1 migrant (coho smolts)	
THM Score	Rel Survival	THM Score	Rel Survival
>85	1.00	>85	1.00
75 - 84	0.96	75 - 84	0.97
65 - 74	0.93	65 - 74	0.94
55 - 64	0.89	55 - 64	0.91
50 - 54	0.86	50 - 54	0.89
45 - 49	0.82	45 - 49	0.86
40 - 44	0.79	40 - 44	0.83
35 - 39	0.75	35 - 39	0.80
30 - 34	0.71	30 - 34	0.77
25 - 29	0.68	25 - 29	0.74
20 - 24	0.64	20 - 24	0.71
15 - 19	0.61	15 - 19	0.69
10 - 14	0.57	10 - 14	0.66
5 - 9	0.54	5 - 9	0.63
< 5	0.50	< 5	0.60

As Applied to Nearshore Assessment units

Transient rear (0 age chinook)		Age-1 migrant (coho smolts)	
THM Score	Rel Survival	THM Score	Rel Survival
>50	1.00	>50	1.00
45 - 49	0.96	45 - 49	0.97
40 - 44	0.93	40 - 44	0.94
35 - 39	0.89	35 - 39	0.91
30 - 34	0.86	30 - 34	0.89
25 - 29	0.82	25 - 29	0.86
20 - 24	0.79	20 - 24	0.83
18 - 19	0.75	18 - 19	0.80
16 - 17	0.71	16 - 17	0.77
14 - 15	0.68	14 - 15	0.74
12 - 13	0.64	12 - 13	0.71
10 - 11	0.61	10 - 11	0.69
8 - 9	0.57	8 - 9	0.66
6 - 7	0.54	6 - 7	0.63
< 6	0.50	< 6	0.60

Table C-13. Estimates of estuarine area for WRIA 8 streams.

Estuary	Scenario	Length (m)	Width (m)	Area (m^2)
Lake Washington	Template	1,290	210	270,900
	Current	1,290	210	270,900
Pipers Creek	Template	160	5	800
	Current	160	4	640
Shellberger Creek	Template	225	20	4,500
	Current	225	10	2,250
Shell Creek	Template	50	5	250
	Current	50	4	200
Perrinville Creek	Template	50	4	200
	Current	50	3	150
Lund's Creek	Template	64	5	320
	Current	64	4	256
Norma Creek	Template	15	5	75
	Current	15	3	45
Picnic Creek	Template	97	5	485
	Current	97	4	388
Big Gulch Creek	Template	30	5	150
	Current	30	4	120

Appendix C-5: WRIA 8 Habitat and Hatchery Scenarios:

Potential Implications of Alternative Population Structures for Chinook Conservation and Recovery in WRIA 8

Can move down scenarios but decisions cannot be reversed

Genetically Distinct Populations: "What If" Scenarios	Potential Implications for WRIA 8 Habitat Strategy to Meet Steering Committee's Viable Chinook Population Objectives	Potential Hatchery-Related Issues
Scenario A (Current WRIA Plan): 1. Cedar (presumed to have greatest genetic independence) 2. North Lake Washington (closely related to Issaquah Hatchery population, but potentially maintaining some independent characteristics) 3. Issaquah (heavily influenced by hatchery)	• Broadest ramifications for habitat actions requiring most comprehensive protection and restoration actions of all scenarios (as proposed in 11/04 Draft Plan) • Different strategies suited to different populations: 1. Initial overall focus on Cedar, emphasizing improvements to productivity and diversity; 2. North Lake Washington actions emphasize both productivity and spatial distribution (i.e., North, Little Bear, Kelsey and Evans, as well as Bear/Cottage Creek); 3. Issaquah the third priority for restoration (protection, land use and outreach actions remain equal), because of hatchery influence, population has lowest risk of extinction, best overall existing habitat	• "Segregated" current definition of hatchery operations (main objective is to minimize interactions with wild fish) • Current habitat productivity may be so low that reduction in contribution rates could increase extinction risk. If so, hatchery support may be necessary to rebuild the population • Risk that high stray contributions to naturally spawning populations may reduce potential to maintain genetically diverse populations and local adaptations. • To meet HSRG goals for a low contribution rate and minimizing the risk of extinction for naturally spawning Chinook (NOR), natural production would need to be increased.
Scenario B (Current TRT Position): 1. Cedar (presumed to have greatest genetic independence) 2. Sammamish (hatchery-influenced, a combination of Issaquah and North Lake Washington)	Changes and narrows focus of protection and restoration actions, vs. Scenario A: 1. Increased emphasis on Cedar population overall, because of hatchery influence and lower risk for Sammamish 2. Reduced emphasis on spatial distribution in Little Bear, North, Kelsey and Evans, as population includes Issaquah and is not as constrained as Scenario A. 3. Increased emphasis on restoration in Issaquah Creek and Bear/Cottage Creeks, to support increased natural production and increased genetic fitness	• Either Integrated or Segregated Hatchery designation. • Under an integrated program, hatchery broodstock from each population would be managed separately from one another to maintain two genetically distinct populations.
Scenario C: 1. WRIA 8 (Cedar, North Lake Washington, Issaquah are all heavily hatchery-influenced populations)	• Habitat actions may narrow to target those areas that have the most potential to protect or restore habitat capacity and productivity. For example, protection actions could target existing sources of productivity, while restoration actions might focus on migratory and rearing corridors. • Habitat actions might be less geographically diverse under this scenario.	• "Integrated" hatchery management would be applicable under this scenario. • To meet HSRG goals for a low stray contribution rate and minimize the risk of diminished fitness of the naturally spawning Chinook, habitat improvements to increase natural production would be necessary.

Appendix C-5: WRIA 8 Habitat and Hatchery Scenarios:

Potential Implications of Alternative Population Structures for Chinook Conservation and Recovery in WRIA 8

Technical Appendix C-6:

WRIA 8 Ecosystem Diagnosis and Treatment (EDT) Habitat Model
Stream Reach Description for Chinook Tier 1 and Tier 2 Sub-Areas

This appendix includes stream reach descriptions for Chinook streams modeled using EDT. The maps that accompany these descriptions are available at: http://dnr.metrokc.gov/Wrias/8/wria8_longterm_plan.htm

Reaches for the following streams are described in this Appendix:

- Bear Creek, Cottage Creek, and Evans Creek
- Cedar River and Chinook-bearing tributaries
- Issaquah Creek and Chinook-bearing tributaries
- Kelsey Creek and Chinook-bearing tributaries
- Little Bear Creek and Chinook-bearing tributaries
- North Creek and Chinook-bearing tributaries
- Sammamish River

Bear Creek Revised - Fall Chinook

Reach code	No.	Stream	Geographic area	Reach location/description	Length (meters)
Sammamish-1A	1	Sammamish River	Sammamish-1	Mouth to upper extent template delta (68th St Bridge)	628
Sammamish-1B	2	Sammamish River	Sammamish-1	Upper extent template delta (68th St Bridge) to 96th St Bridge	3,395
Sammamish-2	3	Sammamish River	Sammamish-2	96th St Bridge to North Creek Confluence	3,218
Sammamish-3A	4	Sammamish River	Sammamish-3	North Creek Confluence to 175th St (downstream end of agriculture area)	2,381
Sammamish-3B	5	Sammamish River	Sammamish-3	175th St (downstream end of agriculture area) to 145th (agriculture area)	9,783
Sammamish-4A	6	Sammamish River	Sammamish-4	145th to 116th St (Redmond City Boundary)	3,427
Sammamish-4B	7	Sammamish River	Sammamish-4	116th St (Redmond City Boundary) to lower end City of Redmond urban area (Willow Golf Course)	6,613
Sammamish-5	8	Sammamish River	Sammamish-5	Lower end City of Redmond urban area (top of Willow Golf Course) to confluence Bear Creek	4,827
Bear-1	9	Bear Creek	Bear-1	Bear Creek from mouth to bottom of restoration reach	1,014
Bear-2	10	Bear Creek	Bear-2	Bear Creek from bottom of restoration reach to RR tracks (WDFW trap)	386
Bear-3	11	Bear Creek	Bear-3	Bear Creek from RR tracks (WDFW trap) to Avondale Rd Crossing (potential restoration reach)	821
Bear-4	12	Bear Creek	Bear-4	Bear Creek from Avondale Rd Crossing (potential restoration reach) to Evan Cr confluence	1,142
Bear-5	13	Bear Creek	Bear-5	Bear Creek from Evans Cr confluence to Trailer Park (Keller Farm reach)	595
Bear-6	14	Bear Creek	Bear-6	Bear Creek from Trailer Park (top Keller Farm reach) to Cottage Lake Creek	4,972
Bear-7	15	Bear Creek	Bear-7	Bear Creek from Cottage Lake Creek to 133rd St	1,931

				(King County gage site)	
Bear-8	16	Bear Creek	Bear-8	Bear Creek from 133rd St (King County gage site) to 141st crossing	1,448
Bear-9	17	Bear Creek	Bear-9	Bear Creek from 141 St crossing to top end of beaver pond complex	563
Bear-10	18	Bear Creek	Bear-10	Bear Creek from top end of beaver pond complex to confluence with Struve Creek	547
Bear-11	19	Bear Creek	Bear-11	Bear Creek from confluence with Struve Creek to 158th Crossing	1,142
Bear-12	20	Bear Creek	Bear-12	Bear Creek from 158th Crossing to 160th crossing (lower end beaver pond complex)	274
Bear-13	21	Bear Creek	Bear-13	Bear Creek from 160th crossing (lower end beaver pond complex) to top of beaver pond complex	1,464
Bear-14	22	Bear Creek	Bear-14	Bear Creek from top of beaver pond complex to upper extent coho in Bear Creek (0.5 miles upstream of Woodinville-Duvall Rd)	1,110
Evans-1	23	Evans Creek	Evans-1	Mouth to 188th Street	306
Evans-2	24	Evans Creek	Evans-2	188th Street to Union Hill Rd Crossing	998
Evans-3	25	Evans Creek	Evans-3	Union Hill Rd Crossing to 196th St Crossing	161
Evans-4	26	Evans Creek	Evans-4	196th St Crossing to 196th St Crossing - Redmond Fall City Rd	2,156
Evans-5	27	Evans Creek	Evans-5	196th St Crossing & Redmond Fall City Rd to Redmond-Fall City Rd Crossing (downstream of 208th)	1,175
Evans-6	28	Evans Creek	Evans-6	Redmond-Fall City Rd Crossing (downstream of 208th) to Redmond-Fall City Rd Crossing (upstream of 208th)	257
Evans-7	29	Evans Creek	Evans-7	Redmond-Fall City Rd Crossing (upstream of 208th) to 224th St Rd Crossing	2,462

Cottage-1	30	Cottage Lake Creek	Cottage-1	Cottage Creek from mouth to Avondale Way crossing	821
Cottage-2	31	Cottage Lake Creek	Cottage-2	Cottage Creek from Avondale Way to beginning of good quality habitat	1,287
Cottage-3	32	Cottage Lake Creek	Cottage-3	Cottage Creek from beginning of good quality habitat to 2nd Avondale Way crossing	1,706
Cottage-4	33	Cottage Lake Creek	Cottage-4	Cottage Creek from 2nd Avondale Way crossing to begin wetland below lake (upper extent chinook)	1,625
Cottage-5	34	Cottage Lake Creek	Cottage-5	Cottage Creek from begin wetland below lake (upper extent chinook) to confluence with Cold Creek	354

Cedar River - Fall Chinook

Reach code	No.	Stream	Geographic area	Reach location/description	Length (meters)
Cedar-1	1	Cedar River	Cedar-1	Cedar River from mouth to Logan St Bridge (RM 1.0)	1,609
Cedar-2	2	Cedar River	Cedar-2	Cedar River from Logan St Bridge (RM 1.0) to I-405 (RM 1.6)	965
Cedar-3	3	Cedar River	Cedar-3	Cedar River from I-405 (RM 1.6) to SR 169 Bridge (RM 4.2)	4,183
Cedar-4	4	Cedar River	Cedar-4	Cedar River from SR 169 Bridge (RM 4.2) to upstream of Landslide (RM 4.7)	805
Cedar-5	5	Cedar River	Cedar-5	Cedar River from upstream of Landslide (RM 4.7) to RM 5.8	1,770
Cedar-6	6	Cedar River	Cedar-6	Cedar River from RM 5.8 to RM 7.3	2,414
Cedar-7	7	Cedar River	Cedar-7	Cedar River from RM 7.3 to RM 8.2	1,448
Cedar-8	8	Cedar River	Cedar-8	Cedar River from RM 8.2 to Cedar Mt Rd (RM 9.4)	1,931
Cedar-9	9	Cedar River	Cedar-9	Cedar River from Cedar Mt Rd (RM 9.4) to RM 10.2	1,287
Cedar-10	10	Cedar River	Cedar-10	Cedar River from RM 10.2 to just downstream of Taylor Cr (RM 12.7)	4,023
Cedar-11	11	Cedar River	Cedar-11	Cedar River from just downstream of Taylor Cr (RM 12.7) to RM 13.8	1,770
Cedar-12	12	Cedar River	Cedar-12	Cedar River from RM 13.8 to RM 14.3	805
Cedar-13	13	Cedar River	Cedar-13	Cedar River from RM 14.3 to RM 15.0	1,126
Cedar-14	14	Cedar River	Cedar-14	Cedar River from RM 15.0 to RR Trail Crossing at RM 16.0	1,609
Cedar-15	15	Cedar River	Cedar-15	Cedar River from RR Trail Crossing at RM 16.0 to RR Trail Crossing at RM 17.0	1,609
Cedar-16	16	Cedar River	Cedar-16	Cedar River from RR Trail Crossing at RM 17 to Arcadia (RM 19.0)	3,218
Cedar-17	17	Cedar River	Cedar-17	Cedar River from Arcadia (RM 19.0) to RR Trail	965

				Crossing at RM 19.6	
Cedar-18	18	Cedar River	Cedar-18	Cedar River from RR Trail Crossing at RM 19.6 to Landsburg Dam (RM 21.7)	1,770
Cedar R Landsburg Dam	19	Cedar River	Cedar R Landsburg Dam	Landsburg Dam on the Cedar River (RM 21.7)	0
Cedar-19	20	Cedar River	Cedar-19	Cedar River from Landsburg Dam (RM 21.7) to RM 22.2	853
Cedar-20	21	Cedar River	Cedar-20	Cedar River from RM 22.2 to RM 23.9	2,800
Cedar-21	22	Cedar River	Cedar-21	Cedar River from RM 23.9 to Barneston Bridge (RM 29.3 - just downstream of Taylor Creek)	8,608
Cedar-22	23	Cedar River	Cedar-22	Cedar River from Barneston Bridge (RM 29.3 - just downstream of Taylor Creek) to RM 31.4	3,379
Cedar-23	24	Cedar River	Cedar-23	Cedar River from RM 31.4 to RM 31.5	177
Cedar-24	25	Cedar River	Cedar-24	Cedar River from RM 31.5 to RM 32.9	2,317
Cedar-25	26	Cedar River	Cedar-25	Cedar River from RM 32.9 to RM 33.2	386
Cedar-26	27	Cedar River	Cedar-26	Cedar River from RM 33.2 to Cedar Falls Powerhouse (RM 33.7)	821
Cedar-27	28	Cedar River	Cedar-27	Cedar River from Cedar Falls Powerhouse (RM 33.7) to RM 34.1	756
Cedar-28	29	Cedar River	Cedar-28	Cedar River from RM 34.1 to Lower Cedar Falls (RM 34.3)	193
Peterson-1	30	Peterson Creek	Peterson Cr	Peterson Creek from mouth to RM 0.5; stream begins to steepen, enters ravine	805
Rock-1	31	Rock Creek	Rock Cr (low basin)	Rock Creek from mouth to foot bridge over creek (RM 0.06).	97
Rock-2	32	Rock Creek	Rock Cr (low basin)	Rock Creek from foot bridge at RM 0.06 to box culvert under SE 248th St t (@ RM 0.15)	241
Rock-3	33	Rock Creek	Rock Cr (low basin)	Rock Creek from SE 248th St Culvert (RM 0.15) to culvert under Cedar River Pipeline (RM 0.27)	434

Rock-4A	34	Rock Creek	Rock Cr (low basin)	Rock Creek from culvert under Cedar River Pipeline (RM 0.27) to RM 0.32	80
Rock-4B	35	Rock Creek	Rock Cr (low basin)	Rock Creek from RM 0.32 to RM 0.43	177
Rock-5	36	Rock Creek	Rock Cr (low basin)	Rock Creek from RM 0.43 to RM 0.65	354
Rock (upper basin)-1	37	Rock Creek (upper basin)	Rock Cr (up basin)	Rock Creek from mouth to 40/18 Rd junction (RM 1.6 Walsh Ditch diversion)	2,639
Taylor (upper basin)-1	38	Taylor Creek (upper basin)	Taylor Cr (up basin)	Taylor Creek (upper basin tributary) from mouth to RR grade/Bridge (RM 0.03)	48

Cedar River Tribs - Fall Chinook

Reach code	No.	Stream	Geographic area	Reach location/description	Length (meters)
Peterson-1	1	Peterson Creek	Peterson-1	Peterson Creek from mouth to RM 0.5; stream begins to steepen, enters ravine	805
Taylor/Downs-1	2	Taylor/Downs Creek	Taylor/Downs-1	Taylor/Downs Creek from mouth to Maxwell Rd Crossing (RM 0.4)	563
Lower Rock-1	3	Lower Rock Creek	Lower Rock-1	Lower Rock Creek from mouth to foot bridge over creek (RM 0.06).	97
Lower Rock-2	4	Lower Rock Creek	Lower Rock-2	Lower Rock Creek from foot bridge at RM 0.06 to box culvert under SE 248th St t (@ RM 0.15)	241
Lower Rock-3	5	Lower Rock Creek	Lower Rock-3	Lower Rock Creek from SE 248th St Culvert (RM 0.15) to culvert under Cedar River Pipeline (RM 0.27)	434
Lower Rock-4A	6	Lower Rock Creek	Lower Rock-4A	Lower Rock Creek from culvert under Cedar River Pipeline (RM 0.27) to RM 0.32	80
Lower Rock-4B	7	Lower Rock Creek	Lower Rock-4B	Lower Rock Creek from RM 0.32 to RM 0.43	177
Lower Rock-5	8	Lower Rock Creek	Lower Rock-5	Lower Rock Creek from RM 0.43 to RM 0.65	354
Lower Rock (upper basin)-1	9	Lower Rock Creek (upper basin)	Lower Rock (upper basin)-1	Lower Rock Creek from mouth to 40/18 Rd junction (RM 1.6 Walsh Ditch diversion)	2,639
Taylor (upper basin)-1	10	Taylor Creek (upper basin)	Taylor (upper basin)-1	Taylor Creek (upper basin tributary) from mouth to RR grade/Bridge (RM 0.03)	48

Issaquah Creek - Fall Chinook

Reach code	No.	Stream	Geographic area	Reach location/description	Length (meters)
Issaquah-1	1	Issaquah Creek	Issaquah-1	Issaquah Creek from mouth to confluence with NF Issaquah Creek	3,057
Issaquah-2	2	Issaquah Creek	Issaquah-2	Issaquah Creek from confluence with NF Issaquah Creek to I-90 Bridge	853
Issaquah-3	3	Issaquah Creek	Issaquah 3-5 (City)	Issaquah Creek from to I-90 Bridge to Juniper St (City of Issaquah)	708
Issaquah-4	4	Issaquah Creek	Issaquah 3-5 (City)	Issaquah Creek from Juniper St (City of Issaquah) to confluence with EF Issaquah Creek	611
Issaquah-5	5	Issaquah Creek	Issaquah 3-5 (City)	Issaquah Creek from confluence with EF Issaquah Creek to Fish Hatchery Weir	1,191
Issaquah Fish Hatch Weir	6	Issaquah Creek	Issaquah-6	Issaquah Creek Fish Hatchery Weir	0
Issaquah-6	7	Issaquah Creek	Issaquah-6	Issaquah Creek from Fish Hatchery Weir to Hatchery Water Intake Fish Ladder	1,191
Hatchery Intake Fish Ladder	8	Issaquah Creek	Issaquah Hatch Diversion	Issaquah Creek Fish Hatchery Water Intake Fish Ladder	0
Issaquah-7	9	Issaquah Creek	Issaquah-7	Issaquah Creek from Hatchery Water Intake Fish Ladder to confluence with Trib 0199	1,496
Issaquah-8	10	Issaquah Creek	Issaquah-8	Issaquah Creek from confluence with Trib 0199 to power line crossing near city boundary	1,352
Issaquah-9	11	Issaquah Creek	Issaquah-9	Issaquah Creek from power line crossing near city boundary to confluence with 15 Mile Creek	2,848
Issaquah-10	12	Issaquah Creek	Issaquah-10	Issaquah Creek from confluence with 15 Mile Creek to confluence with McDonald Creek	998
Issaquah-11	13	Issaquah Creek	Issaquah-11	Issaquah Creek from confluence with McDonald Creek to Cedar Grove Rd	3,138

Issaquah-12	14	Issaquah Creek	Issaquah-12	Issaquah Creek from Cedar Grove Rd to confluence with Holder and Carey creeks	4,521
NF Issaquah-1	15	NF Issaquah Creek	Lower NF Issaquah	NF Issaquah from mouth to 64th St culvert	1,287
NF Issaquah-2	16	NF Issaquah Creek	Lower NF Issaquah	NF Issaquah from 64th St culvert to 66th St (beginning ravine)	531
NF Issaquah-3	17	NF Issaquah Creek	Upper NF Issaquah	NF Issaquah from 66th St (beginning ravine) to bottom of ravine	386
EF Issaquah-1	18	EF Issaquah Creek	EF Issaquah 1 & 2 (City)	EF Issaquah Creek from mouth to Front St Bridge	322
EF Issaquah-2	19	EF Issaquah Creek	EF Issaquah 1 & 2 (City)	EF Issaquah Creek from Front St Bridge to I-90 crossing (beginning confined reach)	1,834
EF Issaquah-3	20	EF Issaquah Creek	Mid EF Issaquah	EF Issaquah Creek from I-90 crossing (beginning confined reach) to High Point	3,749
15Mile-1	21	Fifteen mile Creek	Lower 15 Mile Cr	Fifteen mile Creek from mouth to Issaquah-Hobart Rd crossing	660
15Mile-2	22	Fifteen mile Creek	Upper 15 Mile Cr	Fifteen mile Creek from Issaquah-Hobart Rd crossing to 240th St	1,046
McDonald-1	23	McDonald Creek	Lower McDonald	McDonald Creek from mouth to confluence with trib 0212A	1,062
Holder-1	24	Holder Creek	Lower Holder	Holder Creek from mouth to 276th St crossing (start forested)	2,156
Holder-2	25	Holder Creek	Mid Holder	Holder Creek from 276th St crossing (start forested) to change gradient	1,866
Holder-3	26	Holder Creek	Mid Holder	Holder Creek from change gradient to SR 18 crossing (described as partial barrier)	1,014
Carey-1	27	Carey Creek	Lower Carey	Carey Creek from mouth to 276th St Crossing (culvert looks like juv barrier)	3,298
Carey 276th Culvert	28	Carey Creek	Mid Carey	Carey Creek 276th St Crossing (culvert looks like juv barrier)	0
Carey-2	29	Carey Creek	Mid Carey	Carey Creek from 276th St Crossing (culvert looks like juv barrier) to 204th crossing (passible culvert)	1,303

Carey-3	30	Carey Creek	Mid Carey	Carey Creek from 204th crossing (passible culvert) to Taylor Ditch confluence	2,092
Carey-4	31	Carey Creek	Upper Carey	Carey Creek from Taylor Ditch confluence to falls	563

Kelsey Creek Revised - Fall Chinook

Reach code	No.	Stream	Geographic area	Reach location/description	Length (meters)
Kelsey-1 (Mercer Slough)	1	Kelsey Creek	Lower Kelsey	Kelsey Creek from mouth to I-405 culvert (Mercer Slough). (76-01)	3,218
Kelsy I-405 Culvert	2	Kelsey Creek	Lower Kelsey	Kelsey Creek I-405 obstruction culvert	0
Kelsey I-405 stream reach	3	Kelsey Creek	Lower Kelsey	Kelsey Creek stream under I-405. (76-02)	209
Kelsey-2	4	Kelsey Creek	Lower Kelsey	Kelsy Creek from I-405 culvert to confluence with Richards Creek and Lk Hills culvert (76_03)	644
Kelsey Lake Hills Culvert	5	Kelsey Creek	Kelsey Park	Kelsey Creek Lake Hills Connector Culvert (also confluence of Richards Cr.)	0
Kelsey-3	6	Kelsey Creek	Kelsey Park	Kelsey Creek from Richards Creek (Lk Hills culvert) to confluence with West Trib (76-04)	531
Kelsey-4	7	Kelsey Creek	Kelsey Park	Kelsey Creek from confluence with West Trib to Glenndale Golf Course (76_05)	1,352
Kelsey Golf course control	8	Kelsey Creek	Kelsey Golf Course	Kelsey Creek Grade control obstruction at Glendale Golf Course (from Kit)	0
Kelsey-5	9	Kelsey Creek	Kelsey Golf Course	Kelsey Creek from bottom of Glenndale Golf Course to NE 8th Street - Golf course reach (76_06)	1,255
Kelsey 8th Culvert	10	Kelsey Creek	Kelsey Golf Course	Kelsey Creek culvert at NE 8th Street	0
Kelsey-6	11	Kelsey Creek	Kelsey Golf Course	Kelsey Creek from NE 8th Street to Olympic pipeline structure. (76-07)	901
Kelsey Olympic	12	Kelsey Creek	Kelsey blw Valley Cr	Kelsey Creek grade control structure for Olympic pipeline	0
Kelsey-7	13	Kelsey Creek	Kelsey blw Valley Cr	Kelsey Creek from Olympic pipeline obstruction to confluence with Valley Creek (creek adjacent to Bel-Red Rd)	611

				(76-07)	
Kelsey-8	14	Kelsey Creek	Kelsey abv Valley Cr	Kelsey Creek from confluence with Valley Creek to 148th Ave. NE. (76-08)	981
Kelsey-9	15	Kelsey Creek	Kelsey abv Valley Cr	Kelsey Creek from 148th Ave. NE to Main Street (76-09)	1,239
Kelsey Main St Culvert	16	Kelsey Creek	Kelsey Headwaters	Kelsey Creek long culvert under Main Street and shopping center.	0
Kelsey Main St stream reach	17	Kelsey Creek	Kelsey Headwaters	Kelsey Creek stream reach under Main Street and shopping center to Larson Lake (76_10)	225
Kelsey Larson Lake	18	Kelsey Creek	Kelsey Headwaters	Kelsey Creek from Larson outlet to 156th Ave. SE (76-11)	1,335
Kelsey-10	19	Kelsey Creek	Kelsey Headwaters	Kelsey Creek from 156th Ave. SE to headwaters (76_12)	1,545
Kelsey Richards-1	20	Richards Creek	Richards Cr	Richards Creek from mouth to Bannerwood Park culvert	1,512
Kelsey Richards Culvert	21	Richards Creek	Richards Cr	Richards Creek Bannerwood Park culvert	0
Kelsey Richards-2	22	Richards Creek	Richards Cr	Richards Creek from Bannerwood Park culvert to SE 32nd St	1,931
Valley-1	23	Valley Creek	Valley Creek	Valley Creek from mouth to confluence Sear's Ditch (downstream of SR 520)	579
Valley-2	24	Valley Creek	Valley Creek	Valley Creek from confluence Sear's Ditch (downstream of SR 520) to SR 520	80
Valley Sr 520	25	Valley Creek	Valley Creek	Valley Creek Culverts (?) under SR 520	0
Valley-3	26	Valley Creek	Valley Creek	Valley Creek from SR 520 to 1st LB Tributary upstream of SR 520	80
Valley-4	27	Valley Creek	Valley Creek	Valley Creek from 1st LB Tributary to 2nd LB tributary upstream of SR 520	129
Valley-5	28	Valley Creek	Valley Creek	Valley Creek from 2nd LB tributary upstream of SR 520 to NE 27th St	338
Valley NE 27th Culvert	29	Valley Creek	Valley Creek	Valley Creek NE 27th St Culvert (barrier?)	0

Valley-6	30	Valley Creek	Valley Creek	Valley Creek from NE 27th St to change riparian downsteam of Bellevue Municipal Golf Course (riparian improves upstream this reach)	1,529
Valley-7	31	Valley Creek	Valley Creek	Valley Creek from change riparian downsteam of Bellevue Municipal Golf Course (riparian improves this reach) to Bellevue Municipal Golf Course	740
West Trib-1	32	West Trib	West Trib	West Trib from mouth (Kelsey Cr) to top end of Glendale Golf Course	1,432
West Trib-2	33	West Trib	West Trib	West Trib from top end of Glendale Golf Course to NE 3rd St	418
West Trib NE 3rd Culvert	34	West Trib	West Trib	West Trib NE 3rd St Culvert (barrier?)	0
West Trib-3	35	West Trib	West Trib	West Trib from NE 3rd St Culvert (barrier?) to confluence RB trib just upstream of NE 8th St	740
West Trib-4	36	West Trib	West Trib	West Trib from confluence RB trib just upstream of NE 8th St to confluence Goff Creek	274
West Trib-5	37	West Trib	West Trib	West Trib from confluence Goff Creek to Bellevue-Redmond Rd (upper extent coho potential)	386
Goff-1	38	Goff Creek	Goff Creek	Goff Creek from mouth (West Trib) to 1st RB tributary at ~ 130th Ave NE	901
Goff-2	39	Goff Creek	Goff Creek	Goff Creek from 1st RB tributary at ~ 130th Ave NE to Bellevue Redmond Rd (upper extent coho potential)	338

Little Bear Creek Revised - Fall Chinook

Reach code	No.	Stream	Geographic area	Reach location/description	Length (meters)
Sammamish-1A	1	Sammamish River	Sammamish-1	Mouth to upper extent template delta (68th St Bridge)	628
Sammamish-1B	2	Sammamish River	Sammamish-1	Upper extent template delta (68th St Bridge) to 96th St Bridge	3,395
Sammamish-2	3	Sammamish River	Sammamish-2	96th St Bridge to North Creek Confluence	3,218
Sammamish-3A	4	Sammamish River	Sammamish-3	North Creek Confluence to 175th St (downstream end of agriculture area)	2,381
Little Bear-1	5	Little Bear Creek	L Bear mouth to Hwy 522	Little Bear from mouth to 132nd St Crossing (City of Woodinville)	434
Little Bear 132nd Culvert	6	Little Bear Creek	L Bear mouth to Hwy 522	Little Bear 132nd St Crossing (City of Woodinville)	0
Little Bear-2	7	Little Bear Creek	L Bear mouth to Hwy 522	Little Bear from 132nd St Crossing (City of Woodinville) to Hwy 522 Crossing	1,287
Little Bear 522 Hwy Culvert	8	Little Bear Creek	L Bear Hwy 522 to County line	Little Bear Hwy 522 Crossing	0
Little Bear-3	9	Little Bear Creek	L Bear Hwy 522 to County line	Little Bear from Hwy 522 Crossing to confluence with Rowlins Creek	1,818
Little Bear-4	10	Little Bear Creek	L Bear County line to 228th	Little Bear from confluence with Rowlins Creek to begin industrial reach	531
Little Bear-5	11	Little Bear Creek	L Bear County line to 228th	Little Bear from begin industrial reach (Alpine Rocky Industrial) to confluence Howell Creek (top of industrial area)	1,126
Little Bear-6	12	Little Bear Creek	L Bear County line to 228th	Little Bear from confluence Howell Creek (top of industrial area) to Canyon Park Culvert (potential Brightwater site)	692
Little Bear Canyon Pk Culvert	13	Little Bear Creek	L Bear 228th St to Grt Dane Cr	Little Bear Canyon Park Culvert	0
Little Bear-7	14	Little Bear Creek	L Bear 228th St to Grt Dane Cr	Little Bear from Canyon Park Culvert (upstream end of potential Brightwater site) to	1,014

				confluence with Cutthroat Creek (RB trib)	
Little Bear-8	15	Little Bear Creek	L Bear 228th St to Grt Dane Cr	Little Bear from confluence with Cutthroat Creek (LB trib) to confluence with Great Dane Creek (LB trib)	708
Little Bear-9	16	Little Bear Creek	L Bear Grt Dane Cr to 51st	Little Bear from confluence with Great Dane Creek (LB trib) to Little Bear Rd culvert	1,448
Little Bear Rd Culvert	17	Little Bear Creek	L Bear Grt Dane Cr to 51st	Little Bear Little Bear Rd culvert (barrier?)	0
Little Bear-10	18	Little Bear Creek	L Bear Grt Dane Cr to 51st	Little Bear from Little Bear Rd culvert to 51st St culvert	2,414
Little Bear 51st Culvert	19	Little Bear Creek	L Bear 51st to headwaters	Little Bear 51st St culvert	0
Little Bear-11	20	Little Bear Creek	L Bear 51st to headwaters	Little Bear from 51st St culvert to 180th SE Culvert	837
Little Bear 180th Culvert	21	Little Bear Creek	L Bear 51st to headwaters	Little Bear 180th SE Culvert	0
Little Bear-12	22	Little Bear Creek	L Bear 51st to headwaters	Little Bear from 180th SE Culvert to upper extent coho potential (nr Silver Firs Subdivision)	2,832
Great Dane-1	23	Great Dane Creek	Great Dane Creek	Great Dane Creek from mouth to SR 524 crossing	579
Great Dane SR 524 Culvert	24	Great Dane Creek	Great Dane Creek	Great Dane Creek SR 524 crossing	0
Great Dane-2	25	Great Dane Creek	Great Dane Creek	Great Dane Creek from SR 524 crossing to upper extent coho potential (0.25 miles)	451

North Creek Revised - Fall Chinook

Reach code	No.	Stream	Geographic area	Reach location/description	Length (meters)
Sammamish-1A	1	Sammamish River	Sammamish-1	Mouth to upper extent template delta (68th St Bridge)	628
Sammamish-1B	2	Sammamish River	Sammamish-1	Upper extent template delta (68th St Bridge) to 96th St Bridge	3,395
Sammamish-2	3	Sammamish River	Sammamish-2	96th St Bridge to North Creek Confluence	3,218
North-1	4	North Creek	North Cascadia Reach	North Creek from mouth to top of Cascadia Restoration project	1,335
North-2	5	North Creek	North 2 (Business Prk)	North Creek from top of Cascadia Restoration project to upstream end of business park	2,333
North-3	6	North Creek	North 3	North Creek from upstream end of business park to 228th SE Canyon Park Rd Crossing	1,899
North-4	7	North Creek	North 4 & 5 (Canyon Park)	North Creek from 228th SE Canyon Park Rd Crossing to 208th St Culvert	3,186
North 208th Culvert	8	North Creek	North 4 & 5 (Canyon Park)	North Creek 208th St Culvert	0
North-5	9	North Creek	North 4 & 5 (Canyon Park)	North Creek from 208th St Culvert to 196th St culvert	1,512
North 196th Culvert	10	North Creek	North 6 & 7 (North Cr Regional Prk)	North Creek 196th St culvert	0
North-6	11	North Creek	North 6 & 7 (North Cr Regional Prk)	North Creek from 196th St culvert to confluence Nickel Creek and North Creek Regional Park boundary (John Bailey Rd)	2,220
North-7	12	North Creek	North 6 & 7 (North Cr Regional Prk)	North Creek from confluence Nickel Creek to confluence Penny Creek (begin Mill Creek development around 164th)	1,802
North-8	13	North Creek	North 8 (Mill Cr)	North Creek from confluence Penny Creek (begin Mill Creek development area ~164th) to top end of Mill Creek	1,110

				development area (approx 156th)	
North-9	14	North Creek	North 9 & 10 (McCollum Park)	North Creek from upper end of Mill Creek development area (approx 156th) to just downstream of McCollum Park	2,784
North-10	15	North Creek	North 9 & 10 (McCollum Park)	North Creek from just downstream of McCollum Park to 128th Crossing	644
Silver-1	16	Silver Creek	Silver 1	Silver Creek from mouth to 196th Culvert	1,625
Penny-1	17	Penny Creek	Penny 1 (to pond outlet)	Penny Creek from mouth to Retention pond	853